CHEMICAL ENGINEERING SERIES

CHEMICAL ENGINEERING PLANT DESIGN

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PREFACE TO THE SECOND EDITION

Enough time has elapsed since the first edition so that appreciable contributions to many of the subjects treated in this book have appeared in the technical and trade literature. The effort in the second edition has been to incorporate as much as possible of this new work and information on change in design of plants, processes, and equipment without departing from the original idea of an elementary text. Some parts have been rewritten and several rearrangements have been made in an attempt to achieve greater clarity or simplicity in the presentation.

The principal changes are in the chapters on Development and Plant Location. Minor changes have been made in other chapters where this seemed desirable. A large number of pertinent references have been added to this edition.

The author wishes to acknowledge many helpful suggestions offered by users of the book.

FRANK C. VILBRANDT.

BLACKSBURG, VIRGINIA,
January, 1942.

PREFACE TO THE FIRST EDITION

Chemical engineering design is divided into equipment design and plant design; it is the purpose of this book to deal only with the latter phase of design as applied to the chemical industries. Chemical engineering plant design is neither a unit operation nor a unit process, but must be considered as one of the tools of the chemical engineering profession. As a tool this book is presented as an analysis of the fundamental principles and factors that are involved in the development of a technically and economically efficient plant process from the laboratory stage through the pilot plant stages to the commercial size unit.

The subject matter has been selected and developed with particular reference to advanced students of chemical engineering, recent graduates of such courses, and seasoned professional chemical engineers. The subject matter should also be of interest to executives in the chemical engineering industries who have not been trained in the field of chemical engineering, to serve as a guide for their appreciation of the application of chemical engineering principles to plant design.

For the student in chemical engineering, this book presents an opportunity for coordinating chemical and engineering information by the application of previously gained or readily available knowledge or facts to the design of an assembled chemical engineering plant; the designed plant is based not only upon the application of accurate fundamental principles and data on unit operations to a plant process, but also upon the economic phases of the process, emphasis being placed upon costs as an important factor in plant design.

The correlation of the data obtained through laboratory experimentation into a workable basis for designing a plant for the commercially feasible production of a chemical commodity takes into consideration a thoroughly studied organization of equipment and flow of materials in process and a study of storage and expansion. The writing of specifications for materials and equipment and the study of preconstruction cost accounting are

also considered in the analysis of the submitted design. As presented, plant design is built around a visualization of the process in terms of equipment as well as in terms of chemical reactions. A series of examples have been suggested for consideration as possible laboratory work for class purposes.

The correlation of the material applicable to this tool of chemical engineering brings together from widely scattered sources of information many of the latest concepts dealing with the design of chemical plants. References have been included as a guide for collateral reading. No originality is claimed so far as all subject matter is concerned, as much of the material presented can be found published elsewhere. It is essential that books dealing with unit operations and unit processes must serve as companion texts with this tool of the profession.

Many individuals and corporations have provided material, without which the book would present an incomplete picture of plant design. To give due credit for such assistance, references have been made at appropriate places in the text to those responsible for important facts. The author feels indebted to T. R. Olive of the editorial staff of Chemical and Metallurgical Engineering for many helpful and detailed criticisms and suggestions, especially for the organization of the material in the chapter on selection of equipment; also, the author wishes to express his appreciation for the kind suggestions and aid of Dr. O. R. Sweeney, head of the Department of Chemical Engineering at Iowa State College.

FRANK C. VILBRANDT.

BLACKSBURG, VIRGINIA,
October, 1934.

CONTENTS

CHEMICAL ENGINEERING PLANT DESIGN

CHAPTER I

INTRODUCTION

CHEMICAL ENGINEERING

Chemical Engineer.—The chemical engineer is one who is skilled in design, construction, and operation of industrial plants in which matter undergoes a change.

> Design comes first in the familiar trinity of functions that define the field of chemical engineering. Construction follows; then Operation carries on. But of the three, Design is the really creative function of the chemical engineer. Because it starts at the very beginning of the machine, or the process, or the plant, chemical engineering design underlies practically all industrial progress. So it is that, in today's crisis, industry turns to the chemical engineer for the basic idea, the new viewpoint, the scientific method of attacking the crucial problems of present-day production and distribution. His is a most unusual opportunity. . . . His grounding in the fundamental sciences of chemistry, physics, and mathematics is, after all, the chemical engineer's greatest specific asset. It gives him adaptability lacking in the older professions. It provides a logical approach to the problems of any business—a working procedure for applying new knowledge and principles to industrial practice. More and more this creative function has become a determining characteristic of the chemical engineer. Today it offers him his greatest opportunity in laying out and carrying through the plans for rebuilding industrial prosperity.[1]

These lines, written as industry was dragging the bottom of the depression of 1930–1934, are no less true today. Design will continue to be one of the most important functions of the chemical engineer.

[1] Kirkpatrick, S. D., *Chem. Met. Eng.*, **38**, 185 (1931).

Chemical Engineering Plant Design.—The design of a chemical engineering plant is a fundamental chemical engineering problem; it is essential, therefore, that the chemical engineer should recognize design as his responsibility in connection with chemical plants. Chemical plants may be divided into two classes: (1) those that have grown up without any prearranged plan; and (2) those which have been designed for the purpose for which they are used. The first class provides neither for logical operation nor for logical extension; the second class follows some prearranged plan based upon space requirements, the layout of process equipment, and future expansion. Both building and equipment should be designed to give the most efficient production with a minimum of handling of material in process. Provision should be made for storage, for expansion to fit in with the original arrangement without disturbing the flow of work, and for efficient coordination of process equipment. Other factors that should be considered in the design of building and equipment arrangement include: possible hazards of fire, explosion, chemical injury, injury to the health, the welfare of the worker, economical distribution of process steam and power, and expansion of production.

All other factors being equal, an intelligently and carefully designed plant has every advantage over one that has grown up in a hit-or-miss fashion by alterations and additions. The task of the chemical engineer is to calculate quantities and yields, to consider the handling of materials in process and in storage, and to determine all factors relating to the flow of energy and its most efficient utilization. In addition, he must develop detailed costs of each unit operation so that, even before the plant is in blueprint stage, he will know not only the cost per ton for processing the raw materials, but also the cost per unit weight of material of each operation, such as grinding, crystallization, filtration, evaporation, drying, etc.

The Plan of Attack.—The method of approach toward the solution of any problem cannot always be confined to one attack, but can be resolved in divers ways, depending on the equipment used to solve the problem. As it is in general, this is also true in chemical engineering plant design; furthermore, the methods of approach depend upon the experience and training of the individual chemical engineer. So far as it is possible to give a preconceived plan, the one that follows, which was used

largely in the preparation of this book, is offered as an outline for the initial attack:

A. Foundations.
  1. Building.
  2. Equipment.

B. Drainage.
  1. Building.
  2. Equipment.
  3. Sanitary.

C. Water, steam and chemical piping and pumping.
  1. Piping and installation.
  2. Pumping and installation.

D. Building and power transmission.
  1. Industrial buildings.
  2. Illumination.
  3. Ventilation.
  4. Heating.
  5. Power motivation and transmission.

E. The presentation of the project. The chemical and physical nature of the process involved, with limiting conditions of operation, quality of raw materials and finished products, and market control.

F. Materials, equipment and operations flow diagrams.
  1. Qualitative process flow diagram.
  2. Quantitative process flow diagram.

G. Selection of equipment.
  1. Standard and special designs.
  2. Specifications.
  3. Choice of materials for chemical construction.
  4. Selection of types for service.
  5. Types and capacities of unit operation equipment.

H. Plant layout and assembly.
  1. Equipment location.
  2. Departmental arrangements.
  3. Materials handling; expansion; storage.

I. Preconstruction cost accounting.
  1. Raw-materials costs.
  2. Building costs.
  3. Equipment costs.
  4. Installation costs.
  5. Labor costs.
  6. Power costs.
  7. Water costs.
  8. Maintenance and repairs.
  9. General repairs.
  10. Depreciation.
  11. Overhead.
  12. Cost of production for unit quantity of commodity.

J. Location of the chemical plant.

Value of Sketches.—Fundamentally, a sketch must convey to the chief draftsman a picture of an idea, or group of correlated ideas, from which he is able to design in detail. A well-worded treatise might convey the idea, or part of it, but the draftsman might have difficulty in interpreting the phraseology. Even if it were successful, a lengthy, detailed explanation would probably be required, while "a picture is worth a thousand words." The draftman understands the language of pictures and sketches; to use this medium of engineering conversation reduces the probability of misunderstanding. Frequent conferences are held with the draftsman to avoid errors, but the designer of the plant has less difficulty in conveying his ideas clearly and correctly when he uses the sketching method of conversation. In the development of chemical engineering ideas, line and mind pictures can best be conveyed to the manufacturers of chemical equipment if the chemical engineer will sketch and design the desired thought or idea. A sketch must be in sufficient detail to be clear, exact and complete for proper interpretation and use. It must be workable. Every item sketched must be on a separate sheet with the proper number of views to give a complete picture. Each sketch must be properly labeled and signed to permit its general use on other jobs and to permit ready filing.

Bases for Good Design.—Good designs do not happen; they are founded on well-known, sound principles. To create a good chemical engineering design, it is necessary to possess a thorough knowledge of applied mechanics and properties of materials. An interest in and a genuine liking for chemical plant layout and the solving of engineering problems is requisite, together with a faculty of keen, appreciative observation, and the ability to analyze conditions and data. The chemical engineer accumulates data and determines in minute detail the variables that must be kept under control to ensure economy and success. From these data he makes preliminary designs for the plant and writes specifications for the equipment and the materials needed. He indicates types and sizes of commercial equipment and supplies information for building and often for designing special equipment. The student in design must feel that "every line that he puts down can be interpreted," not only by himself, but also by an engineer or a craftsman. Each line must be so

definite that from it the machinist can turn out a machine or machine part, the carpenter a frame or pattern, the contractor a building. The student must know and have confidence that from his "lines" a workman can complete a piece of work. Also, one must get the habit of visualizing a whole before the thought is put into "lines." In the final analysis, the development through details should be delegated to the draftsman; but a good engineer must himself be a sufficiently good draftsman so that his lines will convey his thoughts clearly for others readily to interpret.

Drawings.—Drawings are made up of views obtained by orthographic projection and arranged in accord with the third

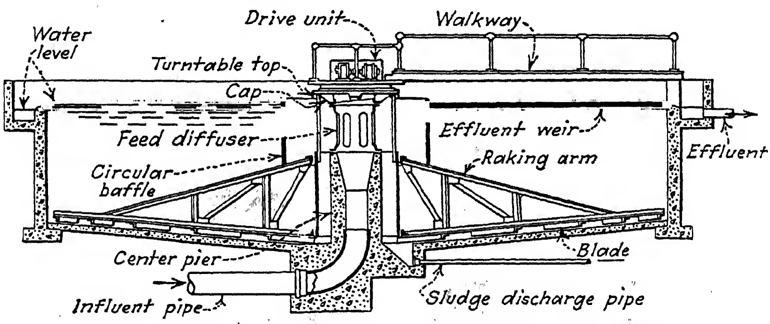

FIG. 1.—Assembly drawing (Dorr Sifeed Clarifier, center drive).

angle. The number of views depends upon the object or construction to be described, two or three generally being sufficient. Each view shows the object as seen from a different position: (1) from above (plan or top view); (2) from in front (elevation, front view); and (3) from one side (elevation, side view). The views are generally arranged as the first position for the right side view. Sometimes, however, it is desirable to revolve the side plane about an axis formed by its intersection with the horizontal plane. This gives the second position for the right side view.

Working Drawings.—Any drawing used to give information and directions for doing work is a working drawing. There are two classes of drawings: (1) assembly drawings and (2) detail drawings. These have been listed as follows:

A. 1. Assembly drawings in outline or section. Design layout drawings. Erection drawings. Skeleton or diagram drawings (see Fig. 1).

2. Assembly working drawings. Part assembly working drawings. Location drawings to show relation of parts with dependent dimensions and fits for two or more details (see Fig. 2).

B. Detail working drawings. General purpose drawings (see Fig. 3).

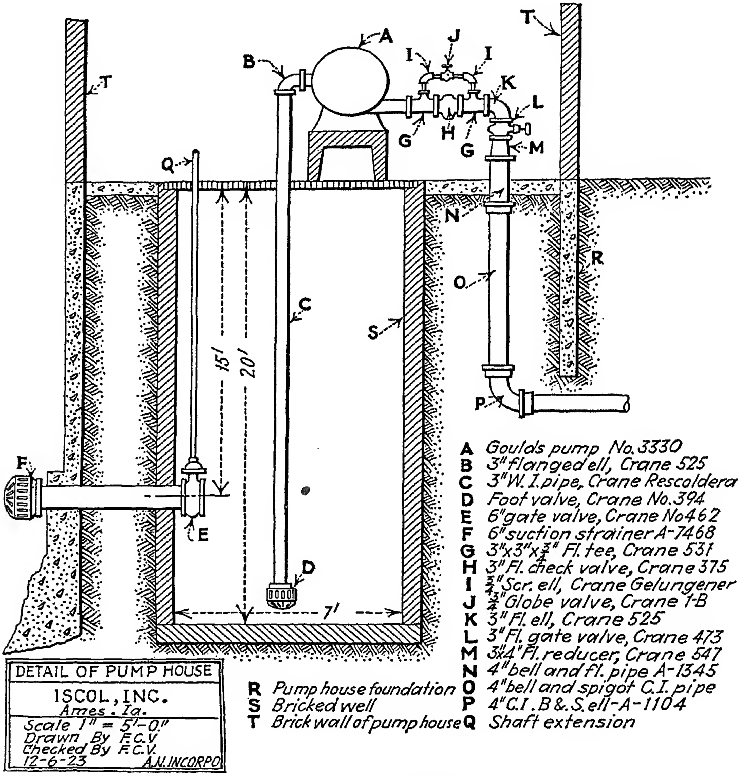

Fig. 2.—Assembly working drawing.

Assembly Drawings.—It is sometimes desirable to give all the dimensions on an assembly drawing so that the equipment layout can be built from it. This gives in part an assembly working drawing. A part or group assembly drawing shows a group of parts in their relation to each other. If dimensioned, no

detail drawing are needed. Process piping or chemical plant diagrams are assembly drawings made to show the sizes, location and arrangement of pipes or equipment. When drawn to scale and completely dimensioned, they are called piping or assembled plant designs. Erection drawings show the order of putting together, dimensions for center distances, location of pumps, presses, pipes, filters, evaporators, etc.

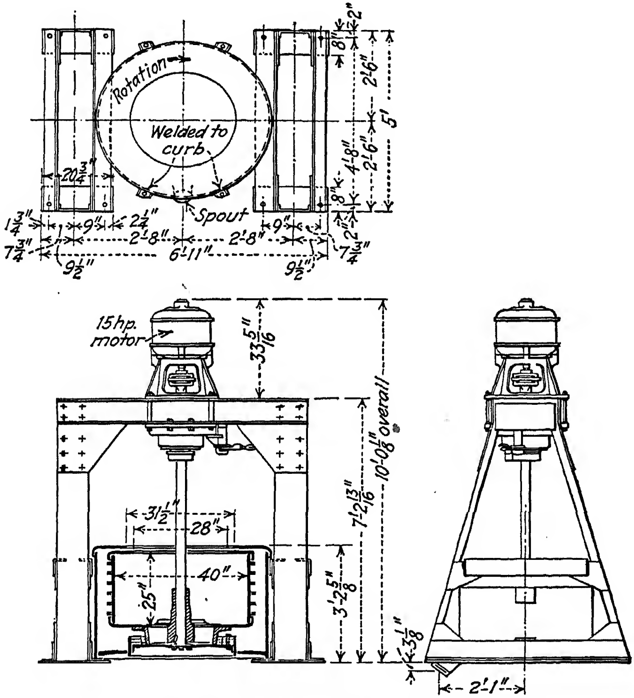

Fig. 3.—Detail working drawing. (*Fletcher Works.*)

Making an Assembly Drawing.—The purpose for which the drawing is desired must first be considered, after which the proper selection of views must be made. The next step is to determine the position of the views on the sheet and the scale to be used.

Locate the main center and base lines for the assembly. Draw the larger stationary parts in the different views. Determine

limiting positions of moving parts if there are any. After this the smaller parts may be drawn very much in the same order as though assembling the actual equipment. Since a small scale is often used, judgment must be exercised as to the amount of detail to be drawn. The character of the equipment must show in the completed drawing. Maximum distances for stationary or moving parts, positions for foundation bolts, locations of shafts, pulleys and piping, and other dimensions having to do with erection or connecting up must be checked and are often given on the drawing.

Every piece of equipment drawn should have a name, a letter, or a number, so that it can be identified. The same name should always be used for a given part. The identification number or letter for a part is generally put in a circle near the name of the part or the views representing it. A legend on the drawing identifies the symbolized pieces of equipment.

Every drawing should have a number and be recorded so as to be easily found. Systems of filing, numbering, recording, transmitting and keeping track of drawings vary with the kind of work and the extent to which the drawings are used.

When a drawing is started the date and draftsman's name should be written on it. When the tracing is completed it should be signed, either in full or by initials, by all who have worked on it, as draftsman, tracer and checker, and by those responsible for its approval. Abbreviations lead to mistakes due to misunderstanding and should not be used when they can be avoided. When changes are made on a drawing they should be indicated. This is often done by enclosing a letter in a circle placed near the change; it is further recorded in the title or record strip with a statement of the change and the date when made.

Detail Drawings.—Detail drawings are generally not considered as part of chemical engineering plant design, but oftentimes, on account of the development of a new piece of equipment, such drawings become a direct responsibility of the chemical engineer. For that reason some of the fundamentals of detail drawings are given here. A detail drawing (Fig. 3) is one that contains the necessary views of each single piece, completely dimensioned and with specifications as to material, machining, etc. In making detail drawings, views should be chosen so as completely to describe the equipment. They

should carry dimensions without crowding and be drawn to a scale that will show the parts clearly. They may be made full size, half size, quarter size or eighth size, but it is desirable to avoid the use of different scales on the same sheet when possible. The detail parts are arranged in the same position and order that they will have in the assembled machine whenever this is possible. A space should be left between views of different pieces, keeping details that are closely related mechanically on the same sheet and making the drawing so complete that no additional information will be required for duplicating the parts shown. Small parts may be grouped together on the drawing, but standard small parts, such as pressure gages, oil and grease cups, lubricators, valves, bolts, screws, ball bearings, etc., which can be described by notes, can be drawn in outline or not at all.

There are three major considerations when making a detail drawing: (1) choice of views; (2) treatment of views; and (3) choice of scale. A freehand layout sketch is very convenient and helpful, especially when standard-size drawing sheets must be used. First locate the main center and base lines for all views. Then draw the preliminary blocking-in lines for all views and finally work out the shape of the object. The general procedure for pencil drawings is to block in with straight lines and large circles. The small circles and fillets are drawn last. If the drawing is not to be inked or traced, the dimension, extension and section lines should be drawn very lightly and the figures and notes added.

Character of Lines.—All pencil lines should be fine, clear and sharp, and for most purposes should be continuous. If drawings are not to be inked the final lines must be distinct but not too wide. Pencil lines for dimensions, sections, etc., should be fine. If the drawing is to be inked, it is not necessary to use different kinds of lines for penciling. The character and weight of ink lines to use are given in Fig. 4. For general drawings a fairly wide line should be adopted as it wears better and gives better results when blueprints are made. Large, simple drawings require a wide line, while small intricate drawings necessitate narrower lines. Drawings that are large and still have considerable detail in parts require more than one width of line.

Lettering and Titles.—A certain degree of expertness in lettering is assumed to be one of the qualifications of present-day

engineers. The necessary training is included in all courses in mechanical drawing.

Titles for drawings vary a great deal, as an inspection of blueprints will show. The titles for detail drawings may or may

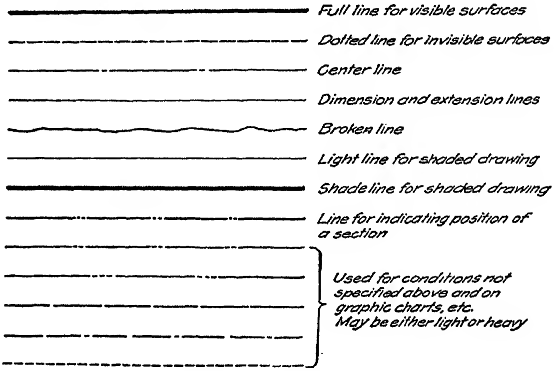

FIG. 4.—Character and weight of ink lines.

not contain the name and location of the company. The name of the piece of equipment, its size and number, the names of details, record of changes, the scale, the date, and the names or initials of the draftsman and engineer can be included. Several

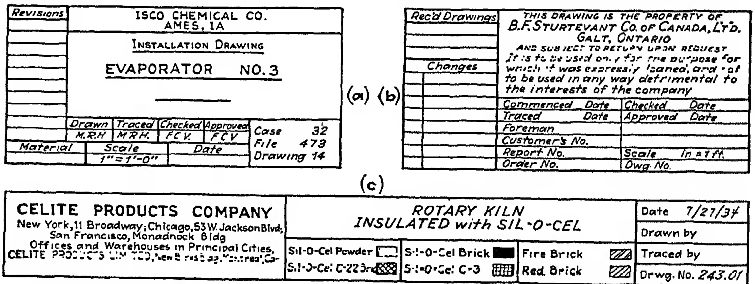

FIG. 5.—Drawing titles. (a) Hand title; (b) printed title; (c) record strip.

types of title are shown in Fig. 5. A hand title, a printed title, and a record strip extending the whole length or width of the sheet are shown.

Common Uses and Treatment of Sections.—When different pieces are shown in a section, they are indicated by changing

the direction of the crosshatching. The width of spacing between section lines is determined by the area to be sectioned, smaller areas having them closer together than larger ones. Different materials are sometimes indicated by different forms of section lining. Figure 6 gives the forms suggested by the American Society of Mechanical Engineers.

The character of sectioning must not be depended upon to indicate the material. A note should always be added when

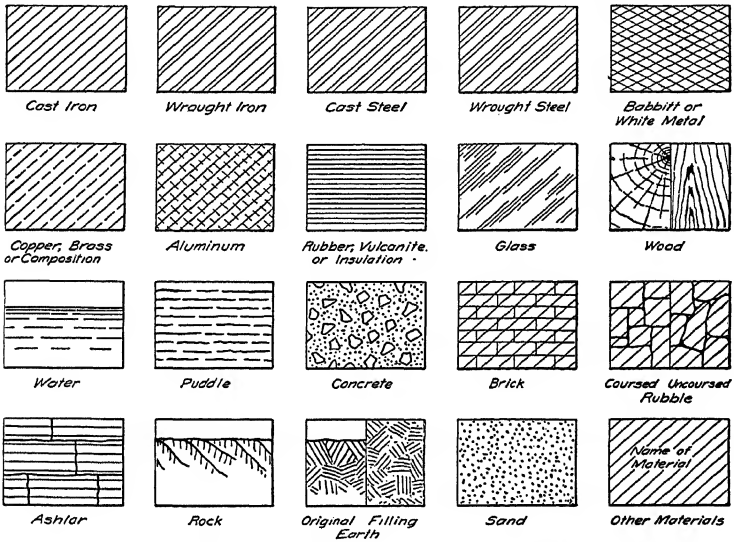

FIG. 6.—A. S. M. E. symbols for sectioning.

the materials are not perfectly evident. The chief value of such sectioning is to make it easier to distinguish different pieces. When small areas are sectioned the surfaces may be "blacked in." When large areas are sectioned the surfaces may be indicated by short lines following the contour lines, sometimes called "herringbone" sectioning. Dotted sections are in the nature of "phantom views" where such lines are used on a full view to distinguish different pieces. This treatment sometimes saves an extra view. A "developed section" is one in which the true length of each part of the cutting plane shows in the sectional view. There are many cases where it is desirable to depart

from true projection in the interests of simplicity and clearness. When dotted lines tend to confuse, they can be omitted.

Kinds of finished surfaces should be indicated by a note. Finished surfaces are indicated with a symbol *f*; finished floor by *f.f.*; grade line by a superimposed "*G*" over "*L*"; feet by the mark (′) and inches by (″), as 5′-3″. The meaning of the different shop operations involved should be found by consulting a good shop handbook.

Dimensioning.—The dimensioning of a drawing is never started until all the views are complete, thus finishing the description of shape. Following this, extension and dimension lines are drawn to indicate the location of dimensions. Finally the arrow points, figures and notes are put on. A preferred system of dimensioning to follow is the placement of lines and figures outside of the object lines, starting from two reference or base lines at right angles to each other. Dimension lines must be kept away from other lines and from each other. Shafts should be dimensioned by giving the diameters and lengths, together with the sizes of keyways and pins, and their location. The position of bearings is sometimes shown by diagonal lines, either plain or blacked in. A note should be used in either case if necessary to make the meaning clear. Positions of pulleys, gears, etc., are located by center lines.

Whatever wood constructions the engineer has to do with seldom require such close dimensions as are common for metal machinery. Timbers are located by centers, and are dimensioned by note, *e.g.*, 2″ × 4″; 4″ × 6″; etc. Sometimes the length is added, as 2″ × 8″ − 6′. Boards are specified by note as 1″ × 10″; ¾″ × 6″; etc. Such sizes are nominal rather than exact as a 2- by 4-in. piece may measure 1¾ by 3¾ in., etc. General over-all dimensions should be given and any other dimensions that must come to a required figure. Such mechanical uses of wood as foundation timbers, cribwork, shelves, wall and ceiling planks to support or hold machines, pulleys, etc., must be drawn and dimensioned by the mechanical draftsman. Nails, screws, bolts, etc., are specified in notes. Nails are specified by a number followed by the letter "d"; 8d, for example, means that 100 nails of this size weigh 8 pounds and is read "8 penny."

CHAPTER II

FOUNDATIONS

The Reference Line.—The first point for consideration in the layout of a chemical plant is the starting or reference point. The horizontal-plane reference lines are longitude and latitude and the vertical is elevation above sea level. Locations are always referred to some definite marking designated by the civil government of the locality. For a building a foundation is necessary, and for a foundation a reference line or datum line is necessary. The engineer's reference line is the "mean sea level." The surface of the ground is too irregular, too unstable to be used as a reference line; therefore, bench marks, laid out by costly surveys by the Federal Government throughout the country and starting at a reference mean sea-level point, are used as the engineer's reference points.

Suppose a foundation is to be laid. A line is run from a bench mark by a surveyor and a stake driven and marked at some point on the property to be used. This is the reference point from which the surveyor obtains measurements for driving stakes in the working area; and from these later the contractor will know how much he must excavate or fill to obtain the desired level for the building operations.

Frost Line.—A foundation must not only be at a given level according to a bench mark, but it must be firm and fixed according to a horizontal line and must not be affected by variations in temperature and rainfall. First, one must consider the *frost line*. A good foundation must go below this to avoid effects of variation in temperature. In Alaska this may run to 10 to 50 ft; at Blacksburg, Va., 15 in. is a safe depth; at New Orleans, 6 in. is sufficient; while at Miami, Fla., the surface is the frost line. Figure 7 gives the mean frost lines for various sections of the United States.

Bearing Load of Soil.—The frost line alone must not be considered, however; a foundation must go down to the frost line, then as much deeper as will permit building upon solid ground.

But the "earth" is only relatively solid; one cannot always build on solid rock. Oftentimes the terrain will not permit such an

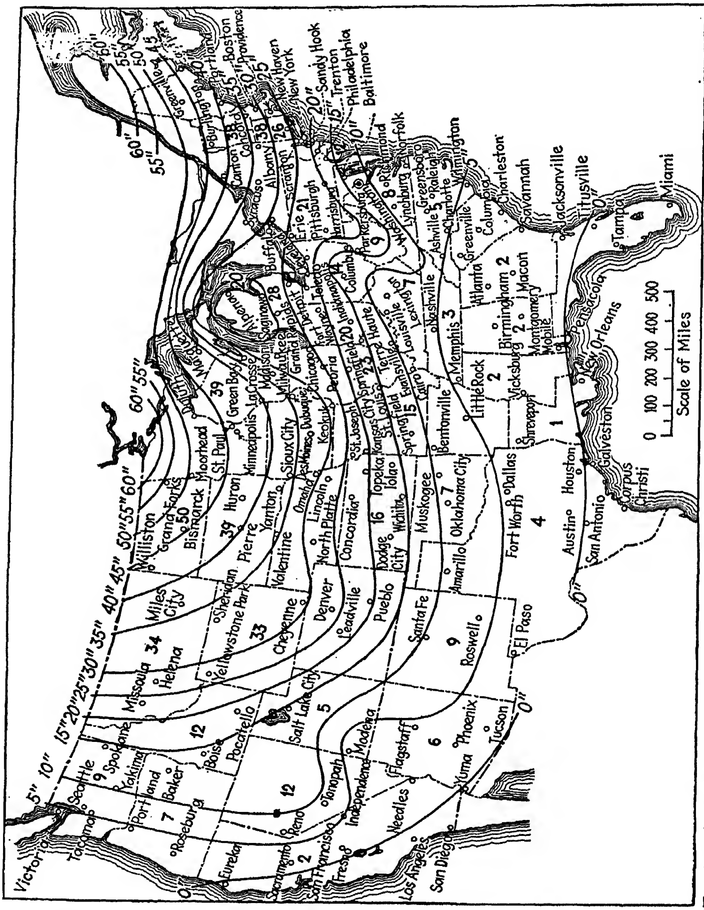

FIG. 7.—Average depth of frost penetration in inches. (*After U. S. Department of Agriculture, Weather Bureau.*)

operation, in which case one must create an artificial base; or one might be fortunate enough to have a location where dry earth supplies the base. How heavy a weight will this earth hold? Or how large does the abutment have to be to support the weight to

be placed upon it? The ground will carry a load dependent upon the nature of the soil. The limits of the weight that ground will sustain are from 0 to 30 tons per square foot. Such data on the varying sustaining powers of soils are to be found in engineering handbooks (see Table 1).

There is a considerable quantity of data which must be collected before a foundation is built. The geology of the locality, the resistance of the rocks, the possibility of slips, and the danger of disintegration of the rock are all matters to be investigated. If there is any doubt as to the material or the condition, borings should be made at the spot and the quality of the earth definitely established.

Sometimes bad soil may necessitate a change of location in the interests of economy. Discovery of near-by deposits of gravel, rock or sand suitable for building purposes may warrant changes in building plans. Water close to the surface necessitates reinforcement of floors for both upward and downward pressures and requires waterproofing.

Igneous rocks are best for foundations and will sustain the greatest weights; swamp loam and quicksands have the lowest values. In such cases it is necessary to add something to sustain the weight placed on the ground. If the soil is quicksand or

Table 1.—Safe Bearing Values of Different Foundation Soils

Material	Tons per Square Foot
Granite rock formation	30
Limestone, compact beds	25
Sandstone, compact beds	20
Shale formation or soft friable rock	8–10
Gravel and sand, compact	6–10
Gravel, dry and coarse, packed and confined	6
Gravel and sand, mixed with dry clay	4–6
Clay, very dry and in thick beds	4
Clay, moderately dry and in thick beds	3
Clay, soft	1–1½
Sand, compact, well cemented and confined	4
Sand, clean and dry, in natural beds and confined	2
Earth, solid, dry, and in natural beds	4
Quicksand, alluvial soils, etc	1

Note.—The foundations for a building housing heavy, vibrating machinery, such as steam hammers, shears, and grinding equipment, should receive some allowance for possible compression and rearrangements of soil owing to the vibrations transmitted through it.

marsh, piles can successively be driven into the sands until the weight necessary to drive the pile a given distance is indicative of, or equivalent to, the value of the weight to be placed upon the soil. A factor of safety must be provided, however. New York builds its skyscrapers with little difficulty. Toledo, formerly a swamp site, limits its skyscrapers, owing to the cost of driving piles into the earth to form the foundation to support the superstructure. A typical example of the need for piling is given by Lundy[1] for the erection of the sulfur developments in Plaquemines Parish, La. Pilings, driven into the swampy soil, are cut off evenly; then reinforcing rods and wire are laid between the stumps; and concrete is poured, providing a concrete island, supported on piling anchored into the soft soil.

The frost line at Norman Wells, Northwest Territory, Canada, near Great Bear Lake, is about 50 ft. below the surface, dating back to the Glacial Age; naturally it never becomes completely thawed out. Each spring the soil is inclined to heave where there is any moisture, and becomes exceedingly spongy. In preparing such ground for a building or equipment foundation, it was necessary first to remove the protecting moss to permit the frozen ground beneath to thaw out to a depth of about 1 ft. The soft earth was then scraped off. River gravel was next laid down, and a grillage of steel members constructed like a mat, extending well beyond the area needed. Concrete was poured upon this to make a platform; nevertheless, all equipment had still to be guyed to prevent tilting should a portion of the ground thaw underneath the platform.

To Determine Burdening Power of Soil.—Suppose the burdening power of the soil is not known. This can be measured by rigging up a test platform:

1. A log of definite cross section is placed endwise against the soil. A platform is built on this and a mast on the platform. Weights are now placed on the platform until it continues to sink slowly from day to day.

2. A second method consists in driving a rod down into the ground and measuring the rate of movement against force of blow.

3. A third method is to use a diamond core drill and note the structure of the substrata from the specimen.

[1] Lundy, W. T., *Chem. Met. Eng.*, **41**, 116 (1934).

Fresh Fills and Excavations.—Judgment is important in solving problems of soil burdens. Fresh fills settle rapidly the first year, appreciably the second, and very little the third. The best policy is to build after the third year. However, buildings are constructed on filled-in swamps and marshes immediately after the fill; in such cases, the buildings are uniformly built to permit unit settling, the building settling as a whole. When the terrain is irregular, problems of excavation should be left to the civil engineer to calculate and to handle. The history of every plant site is of vast importance if irregular settling and misalignment in equipment are to be avoided.

Type of Foundations.—A foundation may vary in the depth to which it is built on account of the specific nature of the structure. The foundation of a house usually extends from 4 ft. below grade to 3 ft. above in order to get below the frost line and yet be high enough to provide for the placement of windows. Also, it may be desired to have the foundation slightly exposed to provide for drainage. Whether the base is to be champed or built straight up depends upon the structure; as a rule, the difference in cost in the extra amount of concrete is not sufficient to offset the cost incident to extra carpentry. It is exceedingly important that the base area be calculated and determined correctly. Also, the equipment must be centered upon the base so as properly to distribute the load, for otherwise the base will shift. Ample strength and abundant and well-distributed bearing capacity must be secured to prevent unequal settlement which would result in cracked walls, broken floors, balky doors and windows, breaks in pipes, misalignment of shafting and equipment, broken equipment, etc. Repairs resulting from such settlement are costly, and attempts at the repair of shifting foundations are likewise expensive and oftentimes unsuccessful. Strength of building and low upkeep depend to a considerable extent on good foundations; skimping in quality of materials and workmanship is not economy. In all cases, a high factor of safety is used in chemical engineering structures, since the small additional cost in construction outweighs the unusual chemical hazards that may otherwise develop.

Multiple Foundations.—For multiple foundations such as piers to support the buildings, the problem of calculation and design is no more difficult than that for a single foundation. It becomes

necessary to consider distribution of unit areas, snow pressure, presence of live or dead weight and location of columns, curtain walls, etc. When regarded from the viewpoint of a multiplicity of single foundations, the foundations for many tanks or for a building are of simple design as shown in Fig. 8.

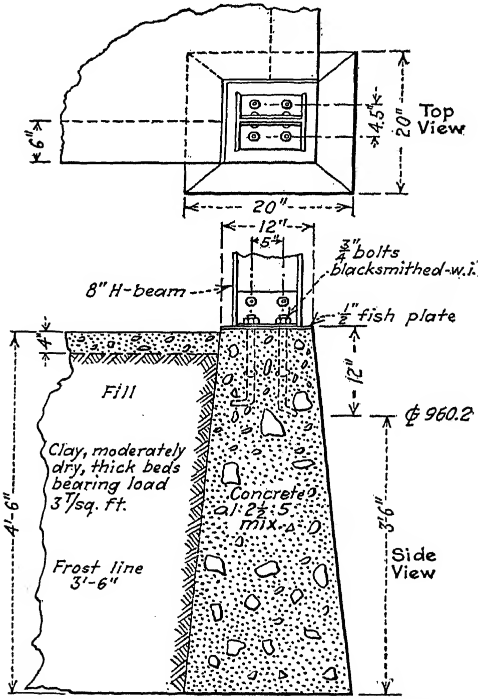

Fig. 8.—Detail of building foundation pier.

Foundations for Equipment.[1]—There are still many points to be considered in the building before one is ready for setting the foundations and floors. At least one of the items of first importance is drainage and the location of the sanitary system; then come water lines, then heavy equipment. One cannot build a chemical engineering building like a warehouse. The idea of

[1] Lee, C. A., *Chem. Met. Eng.*, **46**, 330 (1939).

placing equipment in any sort of building has been discarded by chemical engineers.

When erecting equipment foundations, one must consider the use to which the equipment will be subjected and the possible effects of vibration and shock on the foundations and equipment. Equipment placed upon a pier, foundation or floor of a building may produce sufficient vibrations to render the building and foundations subject to early deterioration. Also, outside interests may desire to be freed from annoying vibrations. In such cases buffering materials such as sulfur, asphalt or timber, or some of the newer vibration-damping materials, must be used for support of the machinery on the concrete piers. Or the equipment may be placed upon piers of such moment and size that they will absorb the shock and vibration. The storage of liquids in tanks requires consideration of a large number of important details before design should be attempted.

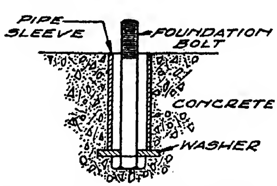

FIG. 9.—Foundation-bolt installation.

An effective method of installing foundation bolts to provide for sufficient play for placing of equipment is obtained by using a pipe sleeve about 2½ diameters larger than the bolt, imbedded in the concrete foundation as shown in Fig. 9.

Steel-tank Supports.—The design of the foundation for a steel tank depends upon the type and design of the tank, which in turn depends entirely upon service. There exist tanks with flat and dished, concave and convex heads; tanks that are horizontal or vertical; tanks for pressure, atmospheric and vacuum service. In the design of the necessary foundations and supports for a steel tank to store tar, fuel oil or benzol, the tank to be placed outdoors, one must first consider the over-all dimensions and the shape of the ends, whether flat, dished or concave. The conventional radius r generally employed for the ends is taken equal to the diameter of cylinder or tank. If $r = \frac{1}{2}$ diameter of cylinder, the head reaches maximum strength for a minimum quantity of steel. The end becomes a hemisphere.

The next consideration is the lugs on which the tank rests upon the supports. These lugs (Fig. 10) are either welded or riveted to the tank and may be either cast or welded.

The foundations should also be as wide as the tank, built below the frost line and of a size dependent on the load. The load is a dead load, and the foundations must be built to carry the maximum expected weight—that of the filled tank. The piers

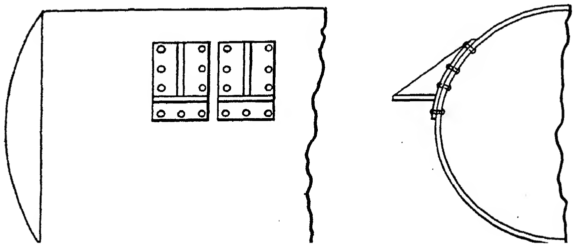

FIG. 10.—Riveted support lugs.

likewise should be built to carry a uniform load. Precautions in construction must be taken to provide for creep and expansion, which will vary considerably with temperature.

Solid Piers.—Styles of foundation vary considerably. One type is the solid concrete or bricked-up pier, shown in Fig. 11. This type must be properly insulated from the tank to prevent the

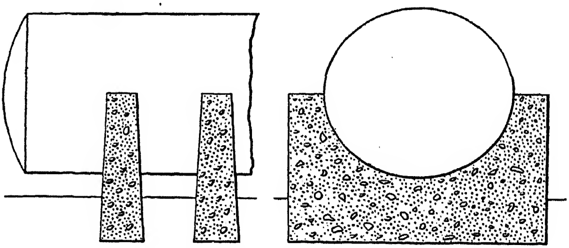

FIG. 11.—Concrete saddle supports.

development of corrosion areas on the tank at points of contact with the pier. Wood, rubber or asphalt can be used for this purpose.

Cribbing Piers.—Timbers can be cribbed, or if the storage tank is small, timbers can be bolted together, the tank resting in the cradle thus provided (see Fig. 12). Such supports provide for movement and shock absorption.

Supporting I-beams Resting on Piers.—This type of support, shown in Fig. 13, permits variation of temperature in the equipment without rupture of the piers by creeping. Usually the tank is anchored at one point, while the other supports or lugs on the tank are free to move on the I-beam. The I-beam is firmly anchored to the supports and the supports to the concrete foundations. The supports can be either standard piping or H-columns.

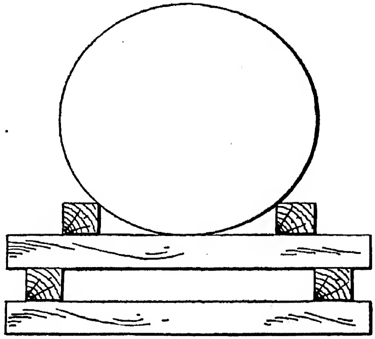

FIG. 12.—Cribbing support.

Vertical Tank Supports.—In order to provide for variations in length or movement of the tank owing to change in temperature, or if storage floor area is limited, vertical tanks may be used with supporting lugs located in the mid-section area, permitting expansion to take place both up and down. A support of this type appears in Fig. 14. Such installation in often used in extraction batteries and stills.

Solid-block Tank Foundations.—Vertical tanks of some importance are oftentimes placed upon single huge blocks of concrete and the tank properly supported by dunnage strips to relieve any possible strain on the chime. The entire weight of the tank contents, therefore, rests upon the bottom. Where several vertical tanks of similar size and shape are to be erected side by side, the monolithic block foundation is built sufficiently large to support the entire assembly. Oftentimes the concrete foundation is extended above the ground several feet more than drainage requirements call for, for the additional concrete costs less than a short section of structural steel.

Wooden Tank Foundations.—Poor foundations are a common cause for leakage of wooden tanks. In the design of good ones, there are three cardinal principles to be observed:

1. The weight must be supported from the bottom only. The staves of wooden tanks must not carry any of the load, and, where the tank is to rest on a level surface, it is best to use

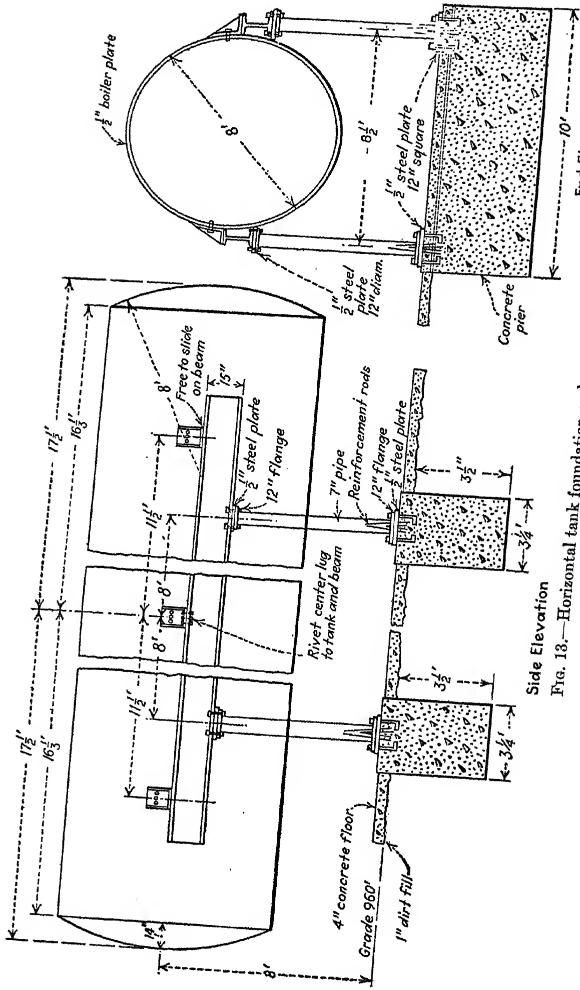

FIG. 13.—Horizontal tank foundation and support.

dunnage strips or subjoists that will support the bottom and raise the ends of the staves (chime) from the foundation.

2. The supporting pieces under the bottom must not be spaced over 18 in. apart (and preferably less), and the bottom boards of wood tanks must run across the dunnage strips or joists supporting them.

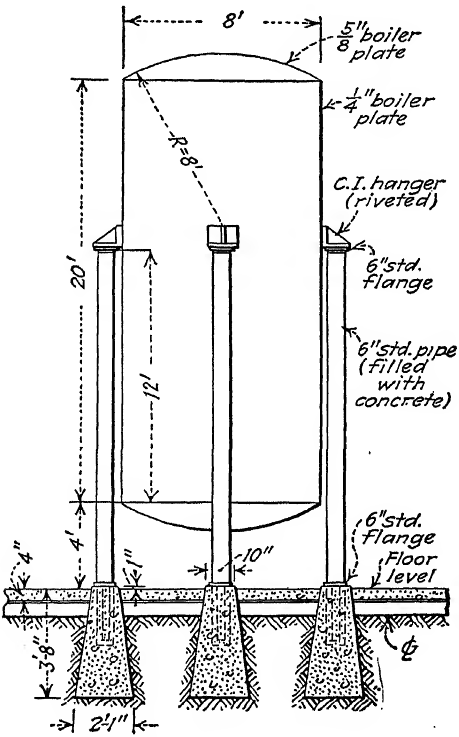

FIG. 14.—Vertical tank support.

3. Concrete foundations, both monolithic and separate piers, must extend below the frost line when on the ground.

Figure 15 shows a standard foundation for tanks on the ground. It consists of concrete walls with wood joists placed across them.

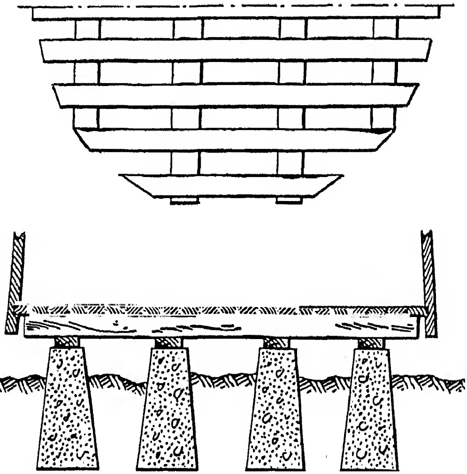

FIG. 15.—Fifty-thousand-gallon wooden tank foundation.

DESIGN OF FOUNDATIONS

In designing concrete foundations the following items must be taken into consideration:

1. The grade level.
2. Effects of frost on the foundation.
3. Bearing load of the soil (see Table 1).
4. Shape and distribution of the load.
5. Weight to be supported by the foundation.
6. Shape of the foundation.
7. Type of concrete mix to use (see Table 2).
8. Shearing and compressive strength of concrete.
9. Dunnage under the load.
10. Placement of reinforcement or anchor rods in foundations.
11. Elevation of the foundation.
12. Thickness of flooring if equipment is inside the building.
13. Type of load on the foundation.
14. Type of equipment support (see Table 3).

TABLE 2.—PROPORTIONING CONCRETE[1]

Mixture	Proportions, cement to sand to stone	Uses	Compressive strength[2]			
			Granite trap rock	Gravel, hard limestone, hard sandstone	Soft limestone and sandstone	Cinders
Rich mixture..........	1:1½:3	Columns, etc., subjected to high stresses	2,800	2,500	1,800	700
Standard mixture......	1:2:4	Reinforced floors, beams and columns, arches or reinforced equipment foundations, tanks, sewers, conduits	2,200	2,000	1,500	600
Medium mixture.......	1:2½:5	Ordinary machine foundations, retaining walls, abutments, piers, building walls, floors, sidewalks	1,800	1,600	1,200	500
Lean mixture..........	1:3:6	Unimportant work in masses, large foundations supporting stationary loads and for backing for stone masonry	1,400	1,300	1,000	400

NOTE.—Strength of concrete in direct shear, 60–80 per cent of compressive strength.

[1] Based on S. E. Thompson, Marks' "Mechanical Engineers' Handbook," 4th ed., p. 708, McGraw-Hill Book Company, Inc., New York, 1941.

[2] Pounds per square inch at 28 days.

TABLE 3.—STANDARD PIPE COLUMN SUPPORTS[1]

(Safe loads in thousands of pounds based on U. S. Department of Commerce, Building Code Committee recommendations)

Nominal pipe size, inches	Outside diameter, inches	Length of column, feet										
		6	7	8	9	10	11	12	14	16	18	20
3	3.5	30.4	28.9	27.3	25.8	24.2	22.5	20.9	17.4			
3½	4.0	37.5	36.0	34.4	32.5	30.8	29.5	27.8	24.4	21.0		
4	4.5	44.4	44.4	42.8	41.1	39.3	37.8	36.0	32.4	28.9	25.3	21.8
4½	5.0	51.6	51.6	51.6	49.9	48.3	46.2	44.5	40.8	37.0	33.4	29.7
5	5.56	60.6	60.6	60.6	60.6	58.1	56.1	54.2	50.3	46.4	42.5	38.6
6	6.625	78.0	78.0	78.0	78.0	78.0	77.3	75.4	71.1	67.2	62.9	58.7
7	7.625	96.9	96.9	96.9	96.9	96.9	96.9	96.9	93.0	88.8	83.9	79.5
8	8.625	117.5	117.5	117.5	117.5	117.5	117.5	117.5	117.5	112.2	107.7	103.0
9	9.625	139.6	139.6	139.6	139.6	139.6	139.6	139.6	139.6	138.0	133.2	129.2
10	10.750	166.9	166.9	166.9	166.9	166.9	166.9	166.9	166.9	166.9	165.0	159.1
12	12.750	204.0	204.0	204.0	204.0	204.0	204.0	204.0	204.0	204.0	204.0	204.0

NOTE.—Safe loads above heavy lines are for values of $1/r$ more than 120 but not over 160, where r is least radius of gyration in inches. Safe loads for concrete-filled pipe columns are available in the same source of information.

[1] From MARKS, L. S., "Mechanical Engineers' Handbook," 4th ed., p. 1617, McGraw-Hill Book Company, Inc., New York, 1941.

CHAPTER III

DRAINAGE

Gases released from drainage systems in a chemical plant, owing to defective design or installation of the waste-disposal piping, endanger the health and even the lives of the workmen. Such gases may arise from both the sanitary and chemical waste systems. Still greater danger and discomfort may exist when the two types of waste, in intermixing, act upon each other to accelerate or decelerate reactions that might occur normally or abnormally. In other cases, such as in food-products plants, the product may be contaminated by gases released from improper waste-disposal systems.

Plumbing Codes in Chemical Plants.—The system for drainage and sewage, together with water supply and water-heating equipment and accessories, is installed by the plumber. This is usually done in accordance with specifications prepared by the architect; in chemical plants, it will be in accordance with the wishes and desires of the operating chemical engineer, since drainage systems are connected directly with equipment. The specifications are also subject to official municipal regulations, because the local authorities assume responsibility for the installation of an efficient and safe system of sanitary plumbing. Systems for handling liquid wastes in chemical plants are not clearly defined in plumbing codes, the solution to the problems being left to the processor (until such time as damage to others may bring the case to the attention of the courts).

Effluent.—The reference point—the lowest point in a drainage system—will in general be one of two types: (1) an effluent pipe into a sand pit, stream, pond or river; or (2) a tap into another sewer. An effluent of the first type must be well protected from washing by construction of a concrete support and spillway, with such a curvature as to direct the drain water out into the stream so that there will be no backwashing and undermining. An effluent of the second type, into a larger drain, is simply

constructed; either the connection to the drain will be made at a preexisting tap, or a cut may be made into the drain and the terminal line cemented into place.

Where the natural drainage is shallow and where rainfall may convert a tract of land into a shallow lake, drainage is difficult. Usual practice is to drop the sewage into a well, then pump from this reservoir to a higher level and at a distance to permit gravity disposal or long-distance pumping. Common practice for chemical sewage is to impound the waste and permit diffusion through the soil or diversion of the impounded waste through a treating plant or bed before it is run off into the natural drainage system.

Capacity.—The first point to consider in determining the location and size of drains of a sewage system is the service to be rendered. The proper size of drain pipes for chemical plants is subject to considerable variance of opinion. Plumbing codes specify 4 in. as common for buried piping and 2 in. as minimum where suspended. The sizes of drains vary with the number of floors. In a chemical plant, however, the question is not one of connecting sanitary branches, but one of disposal of wastes, either corrosive or containing suspended matter. A small pipe allows scouring and prevents the deposition of solids on the sides of the pipe. Calculations of flow must be made if the time required for emptying is an important item in removing wastes from equipment or from an area. Floor drains cannot be considered as all being in use to capacity at the same time unless the specific plant process calls for it. A flow of liquid to fill the pipe but half full should be considered as the carrying capacity of a drainage pipe. In Table 4 will be found data on the carrying capacity of different sizes of sewer pipe for various drops per 100 ft. The pitch of a waste-disposal system is a matter of local health code specifications, but ordinarily this amounts to about ¼ in. per foot.

Tile.—Drain tile and pipe are made of a variety of materials including wood, concrete, steel, unglazed vitrified clay, cast sulfur, terra cotta, salt-glazed vitrified clay or cast iron. Systems installed underground are preferably constructed of bell-and-spigot or hub cast-iron pipe, calked at the joints with lead. In a large number of the cities in the United States this is a requirement. The closing of cast-iron pipes is usually accomplished with oakum and lead, and of ceramic pipes with oakum

and cement. Cast-iron pipe has fewer joints than tile pipe since its sections are generally 5 ft. long, against 2- and 3-ft. lengths of tile. Tile, furthermore, is more susceptible to breakage than cast iron, owing to settling. Terra cotta tile and pipe come in standard sizes, shapes and grades; these are sold locally in 3 ft. lengths, the 6 in. size costing about $0.45 each. Cast iron is manufactured in three grades: light (or standard), heavy and extra heavy. For chemical plants the standard grade is unsatisfactory. The extra heavy is costly, but, where corrosive liquids are dumped into the disposal system, the added life of the extra heavy more than offsets the initial high cost. Heavy pipe is ordinarily considered the normal grade to use where corrosion is not an item. Wrought iron and steel can be used but are considered as highly unsatisfactory in chemical plants. As added protection against corrosion, cast-iron pipe is heavily coated with asphalt.

TABLE 4.—CARRYING CAPACITY OF SEWER PIPE[1]
(Gallons per minute)

Size, inches	Inches fall per 100 ft.							
	1	2	3	6	9	12	24	36
3	13	19	23	32	40	46	64	79
4	27	38	47	66	81	93	131	163
6	75	105	129	183	224	258	364	450
8	153	216	265	375	460	527	750	923
9	205	290	355	503	617	712	1,006	1,240
10	267	378	463	755	803	926	1,310	1,613
12	422	596	730	1,033	1,273	1,468	2,076	2,554
15	740	1,021	1,282	1,818	2,224	2,451	3,617	4,467
18	1,168	1,651	2,022	2,860	3,508	4,045	5,704	7,047
24	2,396	3,387	4,155	5,874	7,202	8,303	11,744	14,466
27	4,407	6,211	7,674	10,883	13,257	15,344	21,771	26,622
30	5,906	8,352	10,233	14,298	17,714	20,204	28,129	35,513
36	9,707	13,769	16,816	23,763	29,284	33,722	47,523	58,406

[1] KIDDER, F. E., and H. PARKER, "Architects' and Builders' Handbook," 18th ed., p. 1751, John Wiley & Sons, Inc., New York, 1931.

Large-sized pipe is commonly made of concrete, cast on the job; or a concreted tunnel is constructed. Oftentimes such large constructed work is bricked in, *e.g.*, the sewers of Paris. The smaller tile can be either straight joint or of the bell-and-spigot type. Building and sanitary codes of municipalities con-

trol the type and size of drain tile permitted, especially where the sanitary sewage of the plant is handled in the municipal system. In general, main soil pipe cannot be less than 4 in.; soil pipe for more than five water closets not less than 5 in.; drain soil lines not less than 4 in.; and main waste pipes not less than 2 in.; when service is required for more than five sinks, urinals or showers, the size should be not less than 3 in. Vent pipes should not be less than 2 in.

A knowledge of building and drainage codes, on the part of the engineer, will assist him readily to specify the construction of the system, from the digging of the trench in the proper place and at the correct drainage depth, to the connection of the reference-point effluent into its ultimate objective.

Cleaning.—Provision for the easy cleaning of sewers must always be made. This is best accomplished by the construction of wells, properly bricked up or concreted, from which inspection of the lines can be carried on. At every bend, change in elevation or terminal point, means must be supplied for inspection and cleaning. Choosing the location of these points is all that it is necessary for the engineer to do, since the details of construction are standard according to certain city codes, and common labor can readily attend to the work.

Should obstructions occur in the systems, there are several ways of loosening and removing them, including (1) jointed rods; (2) the ferret or rat draw line; (3) the shooting of an arrow with an attached string; (4) the use of alternate compression and suction; and (5) chemical treatment.

When a string is drawn through the system, this pulls a heavier cord and this in turn heavier and heavier ropes, until one heavy enough to carry chains for rubbing back and forth can be drawn through. Turbine cutters attached to a hose and propelled by water enable the cleaner to cut away fibrous obstructions such as tree or plant roots. The use of chemicals used in loosening obstructions depends upon the nature of the drainage system. Caustic soda is ordinarily employed to peptize greasy obstructions. One formula consists in the addition of granular zinc or aluminum to dry caustic; another contains calcium carbide. These addition agents react with caustic and water to liberate gases and so prevent setting of caustic. Also, such gases agitate the mass and facilitate removal of the obstruction.

Street mains usually are constructed below the pavement in the center of the street to provide service for both sides of the street. From the lateral tap the sewer line runs to a well before passing curtain walls into buildings, and a well should be provided at the terminus of the sewer to make cleaning possible.

Fittings.—Standard catalogues of fittings should be consulted to determine the available types and sizes of all parts of the drainage system, because the construction of special equipment is costly. Plumbing and sewage contracting has provided an endless choice of materials. Plumbers' handbooks and trade catalogues are the best sources of information on different types of equipment available, giving service requirements, capacities, construction details, essential improvements and comparative costs. The large number of such sources of information available in manufacturers' literature makes it unnecessary that detailed descriptions of such equipment and service be given here.

Both the type and location of service urinals and stools for both men and women employees require prime consideration. It is important that the sanitary service be somewhat removed from the plant processing in order to simplify fittings underground. Process equipment service may interfere with sanitary service in drainage, since equipment drainage may overtax the system at periodic intervals. Therefore, each piece of equipment should drain directly into the main laterals.

Elbows and Y-branches are the most common fittings.[1] These may be screw, flange or bell and spigot. Small-sized fittings, 3 in. and under, are generally screw fittings, and the larger sizes are provided with bell-and-spigot joints. Flanged fittings are special in the small sizes. The elbows are made in 90-, 60-, 45-, 22½-, 11¼-, and 5⅝-deg. angles. Street elbows of 90- and 45-deg. angles are available; 90-deg. elbows with side-and-heel outlets are common. The Y-branches are generally 45-deg., although special types with other angles can be procured, such as the double 90-deg. elbows.

Floor Drains.—Floor drains should be liberally used in a chemical plant. A pitch to the floor of 1 in. in 8 ft. is not sufficient for the rapid runoff so essential to chemical plants, and a

[1] Perry, John H., "Chemical Engineers' Handbook," 2d ed., pp. 922–946, McGraw-Hill Book Company, Inc., New York, 1941.

pitch of from four to six times as much will repay the designer in efficient floor drainage. Floor drains are made with integral traps and cleanouts. If a simple trap is used, a deep seal trap and a cleanout flush with the floor should be provided. Drains for floors not on the ground should be provided with floor seals to prevent leakage seeping around the setting to the floor below.

Pipe Joints.—Pipe joints of the hub type, or bell and spigot, are sealed, first, by packing with oakum, driven in tight, and following this with molten lead. Incidentally, the fact that jute approximates $1 per pound, while lead hovers around $0.084 per pound, makes a calked joint rather costly. Each joint for a 2-in. pipe requires 4 lb. of lead and 0.1 lb. of oakum. For 4-in. pipe the quantities are 7.5 lb. of lead and 0.2 lb. of oakum, while a 6-in. pipe requires 10.25 lb. of lead an 0.3 lb. of oakum. All joints should be given proper attention for perfect sealing. Where small cast-iron piping is used, the joints may be screwed, but these should be specially threaded and the fittings provided with raised internal parts that eliminate the recesses and dams found in the water and steam types of standard pipe fittings. Fittings of this sort give free flow of liquids and reduce the tendency to clog.

Vents.—Where local health codes require that waste disposal piping systems be ventilated, a survey should be made of the specific code to ascertain the correct number and placement of the vents. Oftentimes, the code does not apply to chemical plant wastes; in such cases ample venting should be provided to eliminate the possibility of breaking trap seals on account of any rush of waste when a piece of equipment is voided.

Traps.—Every fixture and each piece of equipment should be separately trapped by a valve or a water-sealing trap placed as close to the fixture outlet as possible, and no trap should be placed more than 2 ft. from any fixture. The sizes of trap for chemical equipment depend upon the desired drain-off, but for sanitary purposes the minimum size is stipulated in the code. Closed traps must be of 4-in. size, while those for sinks, urinals, showers and the like must not be under 2 in.

Traps are known as full S, ¾S, ½S, or P, V, bag, running-Y and grease traps, and combinations, depending upon the use and configuration. Floor drains usually incorporate easy clean-

out traps in their construction to reduce joints and to add serviceability.

Suspended Piping.—Suspended piping should be hung below the ceiling to permit ready examination of all connections. It should be provided with Y-branches at the changes in direction of flow, to permit easy access to the piping for rodding and cleaning. Substantial support should be given all suspended piping in order that vibration and the weight of the pipe may not cause a slow sagging and opening of the pipe at the joints.

Drains under Processing Equipment.—Detail drawings of drainage under equipment must show all construction and sewage lines up to equipment. Large openings and rapid runoff are desirable, so no traps are provided. Cleanout ferrules are always used to permit unscrewing the cap and securing ready access to the drain. Brass traps and ferrules are preferable because cast iron "freezes" on long standing.

A sudden rush of liquids from equipment into the drainage system would cause compression of entrapped gases in the sewer ahead of the stream, and a vacuum behind the stream. Such pulsation drains all the traps and permits permeation of odors and sewer gases. The breather system, by proper installation of vents, is always installed according to code. In order to prevent the back rush of liquids, a palmer or ball check is installed ahead of a condenser. Both check valve and subsequent trap should be accessible for cleanout. The bell of the trap extends down from the perforated or gridded floor screen, and covers a portion of the drain pipe extending above the bottom of the drain pit. More commonly the floor drains, drain screen, bell and outside form of the pit are cast iron.

Sanitary Drainage.—If complex systems of traps and check valves are to be avoided, the sanitary sewage must run into a separate drain and sewer system. However, in municipalities

TABLE 5.—TOILET FACILITIES[1]

Water faucets	1 per 3 persons
Showers	1 per 25 persons
Urinals	1 per 20 persons
Stools	1 per 15 persons
Fountains	1 per 50 persons

[1] EHLERS, V. M., and E. W. STEEL, "Municipal and Rural Sanitation," p. 267, McGraw-Hill Book Company, Inc., New York, 1927.

this cannot be done and both types of sewage are mixed. Urinals, stools, washbasins, showers and fountains are provided according to the needs of the force (see Table 5). Sanitary codes control in a measure what type of service must be provided and, hence, must be consulted. It is sometimes only a matter of choice whether the board fence, galvanized trough, boards on edge, or the antidrip, continuous flushing, automatic, ultrasanitary type of stool be supplied. But to provide clean and sanitary quarters breeds carefulness and clean habits in the workers. Cleanliness and clean appearance, with accessibility, are as important in the plant as in office toilets.

Testing Drainage Systems.—The necessity for testing waste-disposal systems should be evident to chemical engineers. Not only are suspended pipes a source of danger and hazard, but high leakage in underground pipe, through which chemicals may be flowing, insufficiently diluted by other streams, may seriously affect the structure or neighboring land. The water test is easy of application. The engineer should not permit the vertical stack, which connects the first and second floors, to be sealed until he can have the downcomer pipe plugged and all the openings closed except the one to the roof via the vent. Water should then be pumped in and the joints tested for leaks. Either a drop in the water level or visible evidences of leaks at the joints are sought. Additional tamping of the lead usually seals the leak. Plugging of the outlet and filling the underground system with water, with subsequent checking on the water level, enable one to ascertain to what extent underground leaks may exist. Such leaks are difficult to find. Consequently, the engineer should insist on an inspection of the waste piping before covering in the case of underground systems.

Design of a Drainage System.—The points to be taken up in the design of drainage systems, in the order of their consideration, are as follows:

1. Quantity of service demanded.
2. Quality of service demanded.
3. Reference point.
4. Pitch of drain.
5. Effluent protection.
6. Wells and manholes for cleanout purposes.
7. Location of equipment.
8. Location of traps with cleanouts.
9. Location of check valves.
10. Layout in building.
11. Provision for vents.
12. Toilet facilities.
13. Equipment drains.
14. Fixtures.

Symbols for use in drawings are given in Fig. 16.

General Rules of Drainage Design.—Even though the best quality of pipe material be used, the sewage system will give

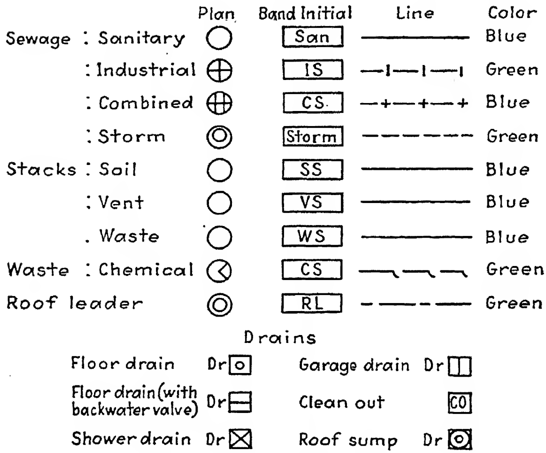

FIG. 16.—Drainage symbols.

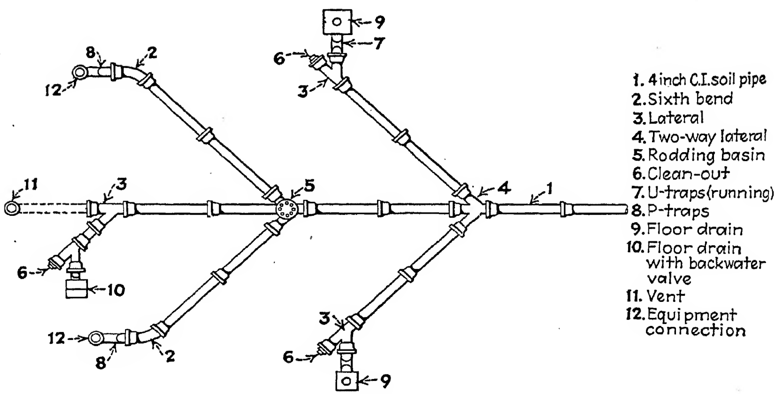

FIG. 17.—Undimensioned assembly plan of drainage system.

unsatisfactory service unless certain precautions are taken in the design and installation. All underground pipe should permit as direct a run of sewage as possible; all changes of direction

should be with long sweeps or curves; and branch connections should be Y-branches (see Fig. 17). Ample provision should be made for cleaning out all lines, for chemical precipitates and sludges may settle in the lines and cause no end of trouble. Y-branches should be used at changes in direction of the lines and each branch provided with a calked-in ferrule, sealed with a close-fitting, screw-in brass plug. If rodding basins are permitted, these should be placed at connecting points of branch sewers to provide access to danger points. Iron rodding basins should be mounted flush with the floor and provided with sealed covers, to be removed only when the plugging of lines calls for cleaning out. After cleaning these should be resealed. A layout of sewer and drainage lines should be made so that proximity to piers or foundations is avoided, in cases where the weight of the pier or foundation would be likely to cause crushing or disruption of the lines.

CHAPTER IV

PIPING INSTALLATION

MATERIALS

Just as arteries and veins are indispensable to the life of human beings, so is piping indispensable to the life of the chemical plant, making it necessary for the chemical engineering designer to know something about pipe and fittings, pumps and their characteristics. A consideration of pumps forms the subject of the next chapter. Piping is a means of cheap transportation in almost every field. Such solids as ashes, sawdust, beet cossettes, cement or molten metals, for instance, are quite as readily conveyed by piping as are ordinary liquids and gases. Piping is the most flexible of all conveying systems, for it can readily be laid uphill, downhill or around corners. The possibilities of piping justify a critical study of each proposed chemical installation to secure the maximum utilization of all its good qualities. First cost, mechanical strength, life, maintenance and the quantity of impurities that will be introduced by the corrosion of the pipe itself are factors that must be considered in the selection of the most economical installation.

The designer of chemical plants has a wide variety of piping materials from which to choose, including steel, wrought iron, cast iron, silicon iron, lead, aluminum, nickel, brass, block tin, tantalum, copper, rubber, Haveg, Bakelite, Lucite, Vinylite and plastics of other origin, Pyrex and other glasses, fused silica, wood, ebonite, chemical stoneware, vitrified clay and special alloys such as Monel metal and the alloys of iron with copper, chromium, molybdenum and nickel.

Selection of Materials.—Cast-iron pipe is cheaply made and is used for underground gas, water and drain pipes, and sometimes for exhaust and low-pressure steam. Wrought pipe, of iron or steel, is most commonly used, especially for high pressures. This pipe comes in random lengths, approximately 20 ft., and is

either lap-welded, butt-welded or seamless. For hot or impure water, brass pipe is preferred since it does not corrode like iron or steel. Spiral-riveted piping is often used for large diameters. In addition, for certain chemical operations, the use of chemical piping made from special alloys, such as Duriron, Nirosta (and other chrome and chrome-nickel irons) and Monel metal, from special pure metals, and from stoneware, hard rubber, wood and industrial glassware, are often necessary. The use of synthetic plastic material for both pipe and fittings has recently been introduced (see also Table 40).

Galvanizing, painting, asphalt or tar treatment of pipes is also resorted to for purposes of combating chemical corrosion.

When superheat is to be maintained, it is recommended to use cast steel to the exclusion of iron castings under pressure for both valves and fittings. Superheated steam frequently causes cast iron to deteriorate very rapidly in strength, to "grow" and change in form, and to check and crack.

Hydraulic pressures at this time are not unusual at 2,000 or 3,000 lb. per square inch. The increase in weight and speeds of machines makes a high-pressure installation in many cases necessary. This is an economy, provided the piping installation has the necessary strength to stand up under the strain. Shock is much more severe than constant pressure, and special precautions in both installation and selection of materials should be taken to provide for it.

Pipe Sizes.—Wrought pipe is specified by its nominal inside diameter for sizes up to 12 in., above which pipe is purchased by the actual external diameter and threading. The Briggs Standard dimensions are used in America. The nominal diameter varies from actual diameter as indicated in Table XIII, Appendix A. Extra-strong and double-extra-strong pipe are made for use at high pressures. The extra thickness is obtained by reducing the inside diameter, the outside remaining constant for a given nominal diameter.

Hydraulic piping is made specially for the specific service demanded. Piping comes in random lengths, varying between 12 and 22 ft., threaded on both ends, with a coupling on one end. Data on service, thickness, weight and strength of standard and de Lavaud centrifugal cast-iron pipe, bell and spigot and flanged, boiler tubes, lap-welded steel pipe, oil tubing, seamless tubing,

hammer-welded pipe, etc., are summarized in Perry's "Chemical Engineers' Handbook,"[1] Sec. 6.

Working Pressures.—Low-pressure steam and water lines, valves and fittings are suitable for working pressures up to 30 lb. steam pressure per square inch.

Low-pressure, standard, and medium valves and fittings will stand a water working pressure 40 per cent greater than the steam working pressure in sizes of 12 in. and smaller. Sizes of 14 in. and larger will stand 20 per cent greater water working pressure than the rated steam working pressure.

Material rated for 250 lb. steam working pressure, and usually designated as extra heavy, will stand a water, oil or gas working pressure of 400 lb. on sizes of 8 in. and smaller, and 350 lb. on sizes of 9 in. and larger.

Hydraulic American standard flanges and flanged fittings, 12 in. and smaller, of 800-lb. grade, of 1,200-lb. grade for extra-strong, and of 3,000-lb. grade for double-extra-strong wrought iron, semisteel and cast steel are recommended for a maximum working temperature of 100°F., for pump columns, oil transmission lines, gas lines and hydraulic service where shock is negligible. The maximum working pressures are as noted, *i.e.*, 800, 1,200 and 3,000 lb., respectively. When subject to shock, such lines are recommended for a maximum pressure of 500, 800, and 2,000 lb., respectively.

FITTINGS

Fittings are made both standard and extra heavy, flanged and screwed, of brass, iron, steel and of special metals. Galvanized and brass fittings generally have screwed ends.

Screwed Fittings.—There are many varieties of screwed fittings available for making all manner of connections, turns, and contacts.

Specifically may be mentioned the following standard screwed fittings which are available as stock and for which description and specifications are given in Perry's "Chemical Engineers' Handbook," Sec. 6, and in the several nationally known pipe, valve and fitting manufacturers' literature: 90-deg. elbow, tee, cross, reducer, Y-bend, return bend, square-head plug for fittings of

[1] PERRY, JOHN H., 2d ed., pp. 869–922, McGraw-Hill Book Company, Inc., New York, 1941.

3 in. and smaller, bar plug for fittings over 4 in. reducer elbows, tees and crosses, female unions, male-and-female unions, railroad unions, gate and glove valves, check valves, couplings and joints of all kinds.

Table 6 gives the specifications for pipe materials and construction as given by Liddell.

Small pipe is generally fitted with screw fittings, with both right- and left-hand threads available. Couplings, particularly, are provided with both right- and left-hand threads to permit the joining of adjacent sections of pipe; a standard union is to be preferred, even at a greater cost, because of better joint and fitting. For reduction, tees, ells, straight reducers or bushings are generally used, but if the opening is small in comparison with size of pipe, a hole may be drilled into the pipe or fitting at the desired point. However, the thickness of the pipe must be such as to give a sufficient number of threads. Tees can be provided with one or two reducing arms, the standard reductions using one stage; in order to get greater reduction, bushings are used. The same rule applies to crosses and ells. Ells are often furnished with angles other than 90 deg. If the fittings are for large pipe, the angles may also be 45, 22½, and 11¼ deg. The introduction in recent years of welding fittings and welding eliminates a number of the fittings ordinarily used. Plugs of a variety of designs are available, but the square head is commonly used because of the ease with which a wrench can be applied.

Flanged Fittings.—Flanged fittings are to be preferred to the screwed fittings for important or high-pressure work. Regular fittings are now made dimensioned according to the American standards devised by a committee of the A. S. M. E. and manufacturers. These standards fix the dimensions for standard-weight fittings (125 lb.), from 1 to 100 in., and for extra-heavy or high-pressure fittings (250 lb.) from 1 to 48 in.

Solder Joints.—"Solder joint" is descriptive of a particular type of connection through which valves and fittings are joined to copper tubing with solder. The valve or fitting and the copper tubing have close-fitting surfaces, and the liquefied solder travels between them by capillary action to give a more or less perfect seal. The use of solder joints for installation of copper piping for steam, hot and cold water, and special industrial servicing, is rapid, reducing friction losses common to screw fittings; copper tubing is sufficiently flexible to eliminate many fittings common to

TABLE 6.—SPECIFICATIONS FOR PIPE MATERIALS[1]

(Key: X.H., extra heavy; w.i., wrought iron; c.s., cast steel; std., standard; c.i., cast iron; galv., galvanized)

Service	Size	Pipe	Fittings	Valves	Joints
1. Steam, above 160 lb., superheated	Small	X.H., w.i.	X.H., c.s.	Special, as below	Screwed
	Large	Std. or X.H., w.i.	X.H., c.s.	Bronze spindles; non-corrosive seats, rings, and plug faces; special necks	Lapped or welded flanges, corrugated steel gaskets
2. Steam, above 160 lb., saturated	Small	Std., w.i.	X.H., c.i.	X.H., c.i.	Screwed
	Large	Std., w.i.	X.H., c.i.	X.H., c.i.	Lapped or welded flange, corrugated steel gaskets
3. Steam, 30–80 lb., saturated.	Small	Std., w.i.	Std., c.i.	Std., c.i.	Screwed
	Large	Std., w.i.	Std., c.i.	Std., c.i.	Faced flanges, rubber wire-insertion gaskets
4. Steam, exhaust	Small	Std., w.i.	Std., c.i.	Std., c.i.	Screwed
	Large	Light cast iron or galv. sheet	Std., c.i.	Std., c.i.	Faced flanges, rubber wire-insertion gaskets
5. Water, warm or cold, underground	Small	C.i. or galv., std.	C.i. or galv., std.	Std., c.i.	C.i., plain flanges, galv. screwed
	Large	C.i., brass and steel	C.i., brass and steel	C.i., brass and steel	Bell-and-spigot, caulked with lead and oakum
6. Water, cold, above ground	Small	Std., black or galv.	Std., c.i. or galv.	Std., c.i. or galv.	Screwed
	Large	Flanged c.i.	Std., c.i.	Std., c.i.	Faced flanges, rubber wire-insertion gaskets
7. Water, hot	Small	Std. brass	Std. or X.H. brass or c.i.	Std. brass or c.i.	Screwed
	Large	Std. brass or c.i.	C.i.	C.i.	Faced flanges, rubber wire-insertion gaskets

[1] After LIDDELL, DONALD M., "Handbook of Chemical Engineering," Vol. I, p. 47; McGraw-Hill Book Company, Inc., New York, 1922.

wrought-iron piping installations. Dismantling for purposes of making additional connections requires only the heating of a soldered joint with the blowtorch. Couplings, tees, elbows, wrought-iron pipe couplings and valves in standard copper tubing sizes are available.

Pipe Joints.—The joints between pipes or fitting are the critical points in a piping layout. Common screwed joints may be used up to $2\frac{1}{2}$ in., with ground unions for the smaller, and flanged joints for the larger sizes. The smallest sizes in which flanged joints may be obtained, except for unions, are 2 in. for superheated and blowoff steam, and $2\frac{1}{2}$ in. for all other servicing. Heavy cast-iron pipe is made with bell-and-spigot, or with flanged joints. Flanges are attached to pipe by screw-fitting the flange to the pipe, by riveting, shrinking and peening, shrinking and rolling, welding or by various special means used by individual manufacturers.

Gaskets used between the faces of the flanges to secure tightness of seal are made of rubber, rubber with wire insert, rubber with canvas insert, asbestos, asbestos with wire insert, corrugated copper (alone or filled with asbestos rope), corrugated steel or special alloy. An excellent compilation of all types of full-faced and ring gaskets, together with formulas for cements to use on specific jobs with gaskets for flanged joints, is given in Perry's "Chemical Engineers' Handbook," pp. 941–944.

Expansion Joints and Bends.—The linear expansion and contraction of pipe occasioned by differences of temperature of the fluid carried, and of the surrounding air, must be taken care of by suitable means. The amount of expansion or contraction in a pipe line of cast iron, wrought iron, steel, brass or copper, in length increase of a pipe 100 ft. long at various temperatures, is given in Table 7. (See Perry's "Chemical Engineers' Handbook," p. 870.)

Proper provision for the expansion and contraction of piping, without permitting undue strain, is made through the use of slip expansion, sliding or swivel joints or of pipe bends. The unbalanced or slip expansion joint should not be used for high-pressure steam if it can possibly be avoided, but if for lack of room no other form can be used, the utmost care must be taken to secure the line to an anchorage which the unbalanced thrust cannot move under any circumstances. Sliding joints are quite compact,

TABLE 7.—THERMAL EXPANSION OF PIPES

Temperature, °F.	Steel	Wrought iron	Cast iron	Brass and copper
0	0	0	0	0
20	0.15	0.15	0.10	0.25
40	0.30	0.30	0.25	0.45
60	0.45	0.45	0.40	0.65
80	0.60	0.60	0.55	0.90
100	0.75	0.80	0.70	1.15
120	0.90	0.95	0.85	1.40
140	1.10	1.15	1.00	1.65
160	1.25	1.35	1.15	1.90
180	1.45	1.50	1.30	2.15
200	1.60	1.65	1.50	2.40
220	1.80	1.85	1.65	2.65
240	2.00	2.05	1.80	2.90
260	2.15	2.20	1.95	3.15
280	2.35	2.40	2.15	3.45
300	2.50	2.60	2.35	3.75
320	2.70	2.80	2.50	4.05
340	2.90	3.05	2.70	4.35
360	3.05	3.25	2.90	4.65
380	3.25	3.45	3.10	4.95
400	3.45	3.65	3.30	5.25
420	3.70	3.90	3.50	5.60
440	3.95	4.20	3.75	5.95
460	4.20	4.45	4.00	6.30
480	4.45	4.70	4.25	6.65
500	4.70	4.90	4.45	7.05
520	4.95	5.15	4.70	7.45
540	5.20	5.40	4.95	7.85
560	5.45	5.70	5.20	8.25
580	5.70	6.00	5.45	8.65
600	6.00	6.25	5.70	9.05
620	6.30	6.55	5.95	9.50
640	6.55	6.85	6.25	9.95
660	6.90	7.20	6.55	10.40
680	7.20	7.50	6.85	10.95
700	7.50	7.85	7.15	11.40
720	7.80	8.20	7.45	11.90
740	8.20	8.55	7.80	12.40
760	8.55	8.90	8.15	12.95
780	8.95	9.30	8.50	13.50
800	9.30	9.75	8.90	14.10

NOTE: The expansion for any length of pipe may be found by taking the difference in increased length at the minimum and maximum temperatures, dividing by 100 and multiplying by the length of the line under consideration.

but the tendency possessed by the male fitting of the unbalanced expansion joint to skew sideways in the female fitting destroys the effectiveness of the expansion unit and results in damage to anchorages and supports. Swivel joints may be used with good results. The balanced expansion joint is a satisfactory straight-way joint, requiring only such anchorage as will react with sufficient force to overcome the friction of the stuffing boxes. A new type of compact, patented expansion joint, which is internally guided, obviates the above criticism and should find more ready adoption. Usually the female fitting is provided with an anchor for the system.

Pipe bends form an important part in any modern piping system. They add flexibility to the line and reduce friction losses. Also they are the most efficient and satisfactory means of taking care of expansions. The flexibility of the bend is determined largely by the radius used. The shorter the radius, the more rigid the bend. Furthermore, extremely short radii greatly increase the chance of "buckling." The weight of pipe to be used in a pipe bend of any particular design is determined by: (1) the pressure under which it is to be operated; (2) the stress occasioned by the expansion to be taken care of by the bend; and (3) the diameter of the pipe.

Where pipe bends are used primarily to take care of expansion and contraction, the use of steel flanges is recommended, regardless of the pressure involved or the type of flange to be used.

Valves.—There are many types of valve, among the more common being globe, gate and plug-cock valves. (See Perry's "Chemical Engineers' Handbook," pp. 935–941.)

The globe valve has a spherical body and a circular opening at right angles to the axis of the pipe. There are several objections to the use of globe valves although they are desirable when throttling is necessary. Among the objections are the resistance they offer to the fluid, and the water pocket present when they are used in steam lines, often a cause of hammering. Seats are replaceable in many manufactured types. Seats include plain flat, parallel, concave or spherical, rounded, square, and bevel types. Any of these forms may be made as a part of the valve body or separate, and either screwed or forced into place.

A gate valve has its opening perpendicular to the direct line of flow so as to offer little or no resistance to the flow, making

this type preferable for most purposes. It is somewhat quicker to open and generally lasts much longer than the globe type.

A plug cock also has its opening perpendicular to the flow. The plug is ground into the seat to give extensive contact.

The variety of valves made available by standard pipe, valve and fitting manufacturers includes such specialties as lever-throttle gate valves (quick-opening valves), expansion valves, check valves (swing or globe vertical spindle), foot valves, pressure-regulating valves, pressure-reducing valves, and Tanner or Stewart two-pressure operating valves.

Among the more recent designs of valve are three types that are important adjuncts to chemical engineering equipment. These include (1) pressure lubricated plug valves, of which the Merco-Nordstrom is typical; (2) the Yarway seatless valve and (3) the diaphragm valve. In the case of the first the lubricating feature permits hydraulic pressure to be applied to release frozen or stuck valves so common in the handling of chemicals. Nordstrom valves are made of various metals and alloys and also of chemical stoneware. The second type, the Yarway valve, is a sleeve that finds favor among operators who are handling viscous or abrasive substances, or masses containing fibrous materials. The third type, the Hills-McCanna Saunders' patent diaphragm valve differs from any conventional valve, being based on a new principle of design, wherein a tight closure is obtained without accurately fitted parts. The valve comprises two body units between which a tough resilient molded diaphragm produces an enveloping action. Valve bodies are available in cast iron, lined with glass, rubber, or lead or any machinable alloy, as well as Haveg or stoneware. Services such as acids, alkalis, viscous substances, semisolids and pulp can be handled successfully.

Valves are operated by wheel or lever; where they must be placed in out-of-the-way places some type of operating mechanism is ordinarily used, such as a floor stand, screw- or bevel-geared wheel, chain pull, or extension handle.

The Everlasting valve is a quick-opening, straight-through gate valve with lever and ratchet control. Its clear-shearing and tight-closing characteristics make it quite common for handling sludges and chemical solutions.

PIPING DESIGN

Basic Principles.—The following principles may be laid down as a guide to competent piping design. (*a*) Use of the proper metals of adequate strength and suitable thickness to provide at least a factor of safety of five and preferably a factor of eight based on the tensile strength of the material. Metals of a reasonably well known endurance or resistance to corrosion should be used. (*b*) Proper flexibility to ensure against the building up of dangerous expansion and contraction strains. (*c*) Proper and adequate support and anchorage to carry safely the maximum possible load and to prevent and completely dampen vibration. (*d*) Properly selected pipe-line joints, dependent upon service requirements. (*e*) Complete control by valves of the proper design, material and workmanship installed in the line at both ends and at all outlets. Ease of access and convenience for proper operation and inspection are essentials. (*f*) Provisions for proper and complete drainage of the line at all times in service or not should be made.

Piping Drawings.—There are several kinds of piping drawings, depending upon the purpose and requirements of the work. When drawn to a small scale, valves and fittings are shown by conventional representations as given in Fig. 18. Symbols for different kinds of piping are given in Fig. 19 and in Table 8. Sometimes a freehand sketch is sufficient, or a line diagram, and on other occasions a large-scale drawing is necessary, consisting of several views of the entire system, together with working drawings of details. A drawing for construction purposes must give complete information as to sizes, position of valves, branches and outlets. A drawing to show the layout of existing pipe lines need not be so complete and is often made to small scale, using single lines to represent the pipe with notes to tell sizes, location and purpose for which the pipe is used. A drawing to show proposed changes should give both existing and proposed piping, using different kinds of lines to distinguish the changes. Dot-and-dash lines, dash lines or colored ink may be used for this purpose. A drawing for repairs may consist simply of the part to be repaired, or may show the location or connection between the repairs and apparatus or other parts of the system. Draw-

ings for repairs should be checked very carefully and should clear just what is to be replaced or repaired.

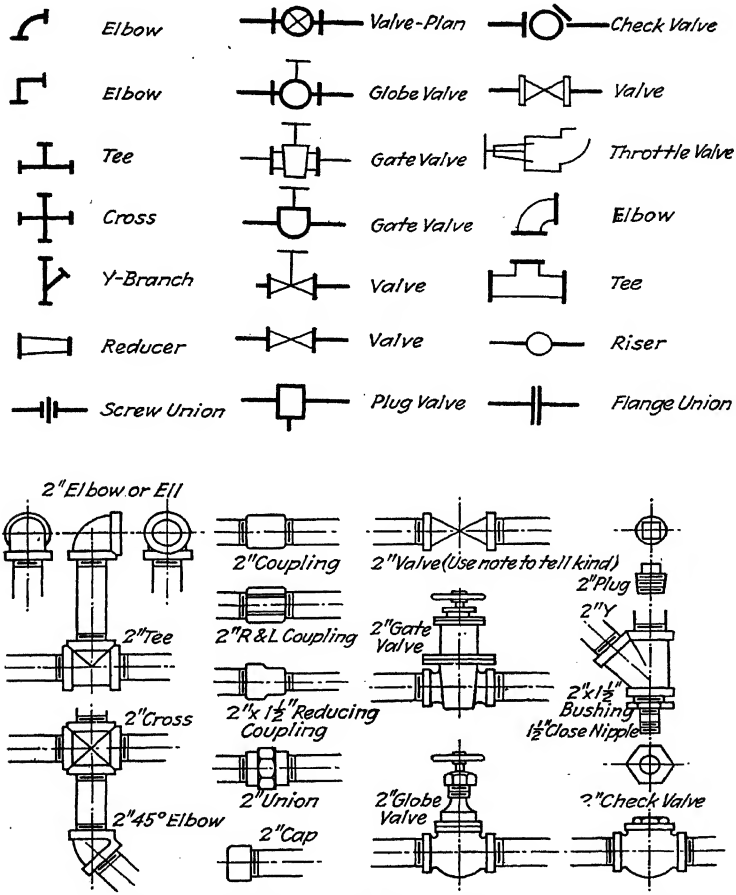

FIG. 18.—Valves and fittings: above, single-line conventions; below, double-line conventions.

The general rules for dimensioning drawings hold for piping plans, but there are additional points that may be mentioned.

Always give figures to the centers of pipe, valves and fittings, and let the pipe fitters make the necessary allowances. If a pipe is to be left unthreaded, it is well to place a note on the drawing calling attention to the fact. If left-hand (L.H.) threads are wanted, this fact should be noted. Wrought pipe sizes can generally be given in a note using the nominal sizes.

Flanged valves, when drawn to large scale, may have the over-all dimensions given, including the distance from the center

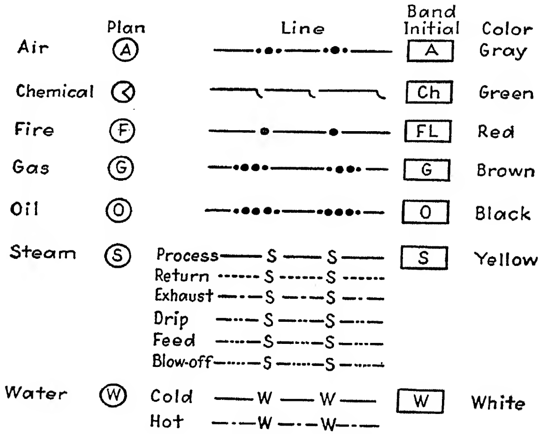

FIG. 19.—Symbols for piping.

to the top of the handwheel or valve stem when open and when closed, the diameter of wheel, etc. Separate flanges should be completely dimensioned as should all special parts. It is necessary that the location of the piping should be definitely given, which means that the parts of the building containing the piping must be shown and must be accurately dimensioned. The relative location of apparatus and pipe connections should be given by measurements from the center lines of machinery, distances between centers of machines, heights of connections, etc.

Final drawings should be made after the engines, boilers and other machinery have been decided upon, for they can then be drawn completely and accurately. At least two views should be drawn, a plan and an elevation. Often extra elevations and

detail drawings are necessary. Every fitting and valve should be shown. A scale of $\frac{3}{8}$ in. to the foot is desirable for piping drawings, when it can be used, since it is large enough to show the system in detail.

TABLE 8.—AMERICAN INSTITUTE OF CHEMICAL ENGINEERS COLOR CODE FOR PIPING[1]

Safe.—Green, aluminum, gray, white (air), black (electricity).
Protective Material.—Blue (water), bright blue (extra precaution).
Extra Valuable.—Deep purple.
Danger.—Yellow (low-pressure steam), orange (high-pressure steam), brown (gas).
Fire Protection.—Red.

[1] *Chem. Met. Eng.*, **34**, 758 (1927).

Piping Sketches.—Sketching is an invaluable aid as a preliminary step in any kind of drawing, and the sketch is often the only drawing needed. One's idea can be made clear and the number and kind of fittings and valves checked up in this way. Where only a small quantity of work is to be done, a sketch may be made and fully dimensioned, from which a list of pieces can be made with lengths, sizes, etc. This will avoid mistakes in cutting, and the sketch shows just how the parts go together without depending upon memory. Such a sketch may be used for making up an order, but in such cases it should be traced on cloth or thin paper so that a blueprint can be made as a record. An "H" or "2H" pencil will give lines black enough to print if ink is not used. The figures, however, should be put on in ink in all cases. If only one or two copies are wanted, carbon paper may be used. Dimensions and notes should be put on as carefully as on a finished drawing. The general procedure is much the same as for other kinds of sketching. First, sketch the arrangement, using a single-line diagram. When this is satisfactory the real sketch may be started by drawing the center lines, estimating locations of fittings, valves, etc., which should be spaced in roughly in proportion to their actual position. The piping, valves, etc., can then be sketched in, using any of the conventions shown in Figs. 18 and 19 or those suggested in the American Institute of Chemical Engineers code for piping (see Table 8). Finally, locate the dimension lines, figures and notes, together with the date and a title of some kind. Pictorial methods can be used to great advantage for sketching pur-

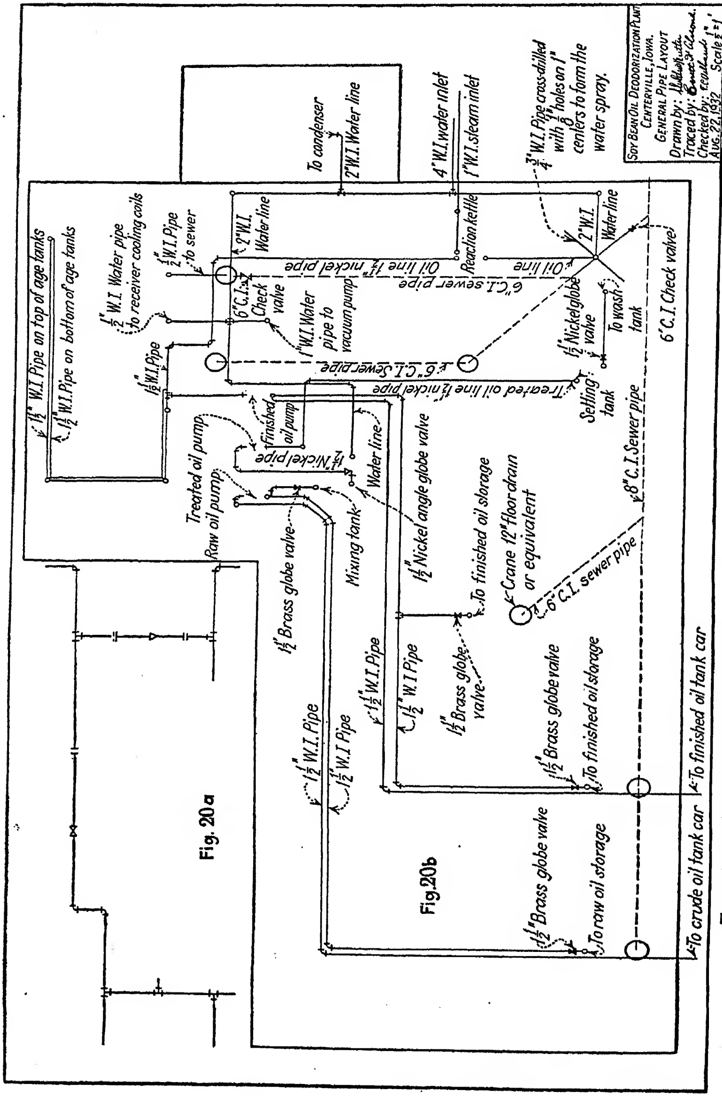

FIG. 20.—*a*, Pictorial single-line sketch of piping; *b*, a developed general pipe-layout sketch.

poses, especially for preliminary layouts, since the directions and changes in levels can clearly be shown.

Developed and Single-plane Drawings.—It will often be found convenient to swing the various parts of a piping layout into a single plane, in order to show the various lengths and fittings in one view. Different methods of showing piping are here illus-

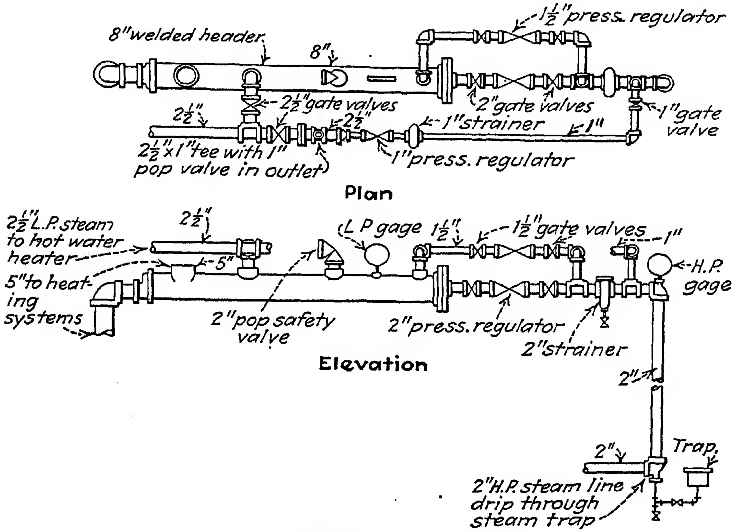

Fig. 21.—Regulating-valve station.

trated; Fig. 20*a* is a pictorial view using single lines to show the position in space; Fig. 20*b* is a developed pipe-layout sketch with the sizes, fittings, etc., written on. In Fig. 21 a developed drawing in two views with complete dimensions and notes is given. Such drawings are valuable when listing or making up an order, as well as for the use of the pipe fitters in doing the work.

PIPE INSTALLATIONS

Piping around chemical and other plants is supported overhead or buried underground, either inside or outside the building.[1]

Underground Installation.—Laying a pipe line in a tunnel (1) reduces the heat losses and insulation costs; (2) does not occupy

[1] Hartford, F. D., *Chem. Met. Eng.*, **39,** 254 (1932).

valuable overhead space; and (3) protects the piping from mechanical injury and freezing. However, it is a good rule to consider some of the disadvantages before installing wrought-iron or steel pipe underground. Leakage, which would be difficult to locate underground, is virtually certain to occur in chemical lines sooner or later. This would require frequent inspection and would make repairs difficult. When piping must pass under certain obstacles, for example, under a concrete roadway or under a shallow stream, it should be installed in such a manner as to permit it to be withdrawn readily for replacement. Underground

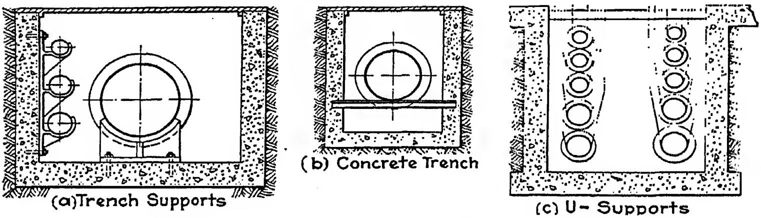

FIG. 22.—Methods of installing pipes in trenches.

piping is also subjected to the usual underground corrosion. The tunnel should be built below the frost line to avoid movement of the line. Pipe supports are easily installed in an underground trench or tunnel and are usually of simple design, either the roller, wedge or common pipe or bar.

Several methods of installing pipes in trenches are given in Fig. 22*a*, *b* and *c*. That of Fig. 22*c*[1] is a satisfactory and economical method in which the two rows of pipes are placed along the trench walls with a working aisle in the center. This aisle should never be less than 18 in. wide, in the clear, and should be wider for larger pipe sizes. The pipes are hung by U-bolts from 4-in., 7½-lb. I-beams, placed 6 to 8 ft. apart along the trench. The beams rest in pockets especially provided for them in the trench walls so that the top of each beam is about 2 in. below the trench cover. The beams are subsequently grouted in.

Steam lines and returns, all hot-water lines and any hot-chemical lines that run outside the power plant or between buildings can be run underground. These lines may be insulated by a special system of underground insulation (see Fig. 23).

[1] KRAMER, B., *Chem. Met. Eng.*, **39**, 456 (1932).

Overhead Installation.[1]—The advantages of placing piping overhead are: (1) ease of inspection for workmanship and leakage; (2) ready availability for repair at any point; and (3) freedom from the usual underground corrosion. The disadvantages of such placement include exposure to freezing, to variations in temperature, and to mechanical injury with attendant danger to passers-by, if the pipe should burst.

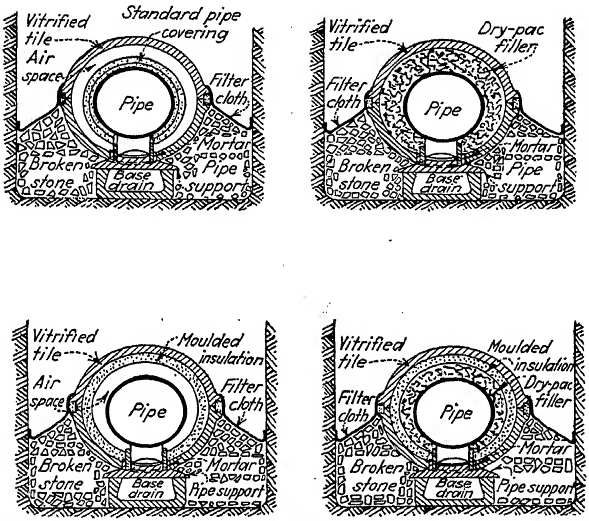

FIG. 23.—Types of insulated underground pipe support. (*Johns-Manville, New York.*)

The simplest type of overhead pipe hanger and support is the extension-bar type which can be used by itself both as a hanger and as a ring when bolted around pipe. Such hangers are furnished in lengths of 5 to 10 ft. and can very readily be cut on the job. The ring-and-bolt type comes next in simplicity. Both are standard equipment and can be obtained from any pipe supply company. Another type is the expansion pipe hanger. The adjustable angle-iron hanger and the adjustable pipe or rod hanger can be used with one or more pipes, usually suspended from beams by beam clamps. The wedge, roller and adjustable roll and stand for support on piers or hangers come in a consider-

[1] HARTFORD, F. D., *ibid.*, p. 255.

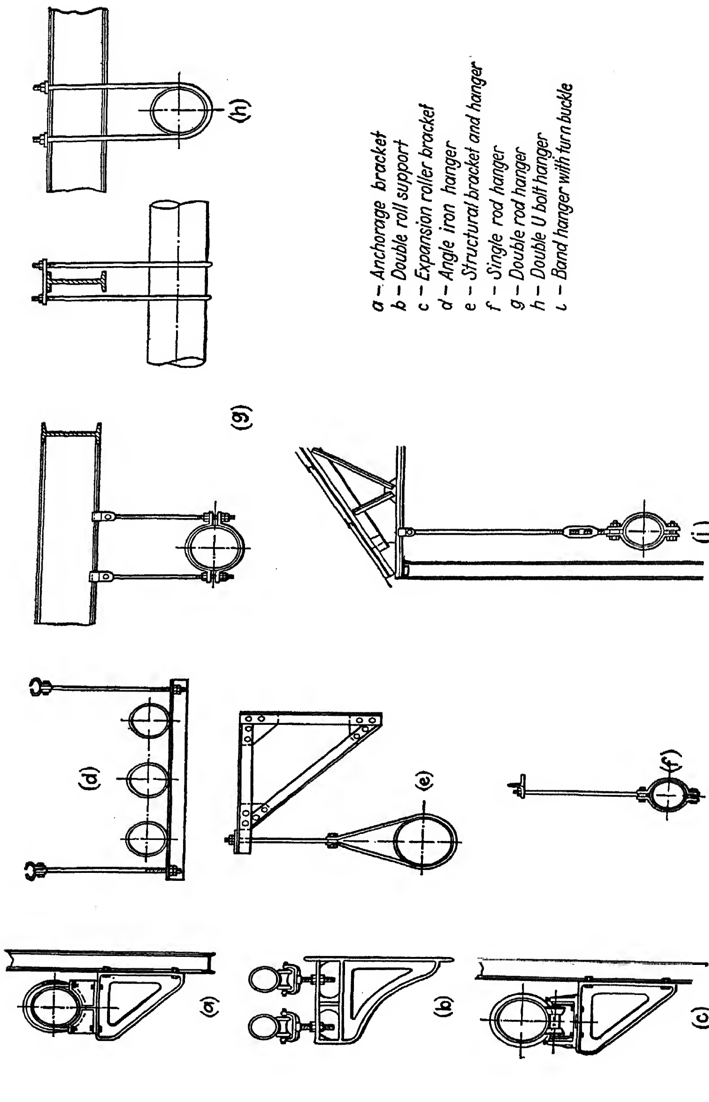

FIG. 24.—Interior pipe hangers.

able variety of patterns. The wall sleeve, the tinned strap and wrought-iron hook are used for pipe supports when strain or weight is of small consequence. Many typical methods of supporting piping are shown in Fig. 24, all of which are self-explanatory. Standard types and special supports can be found in the trade literature catalogues of many prominent manufacturers.

Sometimes it may be possible to carry elevated piping by brackets attached to buildings, but in general the overhead structure will consist of independent posts, or towers with beams or A-frames or trusses, as in Fig. 25.

In designing such structures the clearance and gradient are primary considerations. The headroom required over railroad tracks usually is 22 ft. and may need to be more to accommodate locomotive cranes. Plant roadways or power lines may also require consideration. Overhead piping should be set on a grade so that it will drain to facilitate repairs and to avoid air pockets or low places which may freeze or permit the deposition of sediment.

When the height of the piping above the ground has been decided, the proportioning of spans is the next factor: *i.e.*, whether to use more posts and shorter spans or fewer posts and longer spans. In general, the most economical arrangement is obtained when the total cost of the uprights equals the cost of the trusses. However, buildings or other structures or obstacles along the line will frequently determine the location of the uprights. These uprights may be ordinary wood poles, steel pipes, lattice steel posts, or braced steel towers, depending on the height and loads to be carried. Rigidity is more important than mere load-carrying capacity; a light steel tower, well braced, is less expensive than a single solid column of equal rigidity.

The trusses supporting the piping between uprights take many forms of which those of Fig. 26[1] are examples. These trusses, besides supporting the pipe, should also carry a walkway wherever possible. One of the simplest trusses for carrying a number of small lines, and also providing a working platform, consists of one or two steel stairstringer channels laid flat and trussed with rods underneath. Ordinarily, the length of such a span should

[1] HARTFORD, F. D., *ibid.*

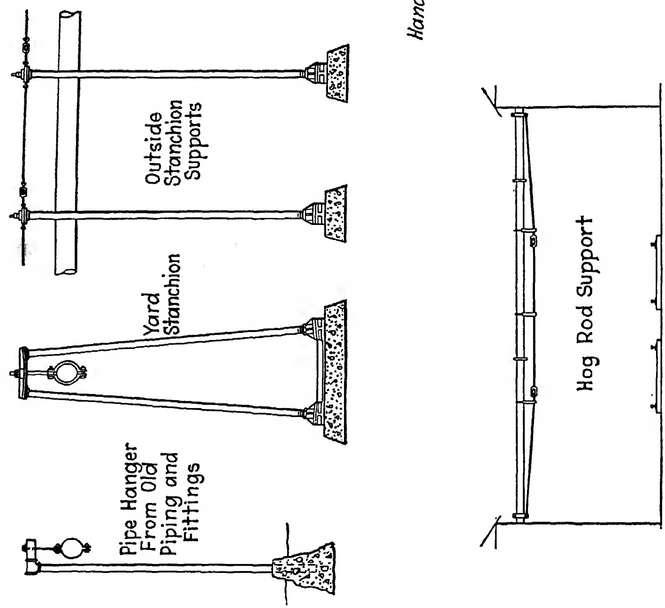

FIG. 25.—Pipe posts and towers.

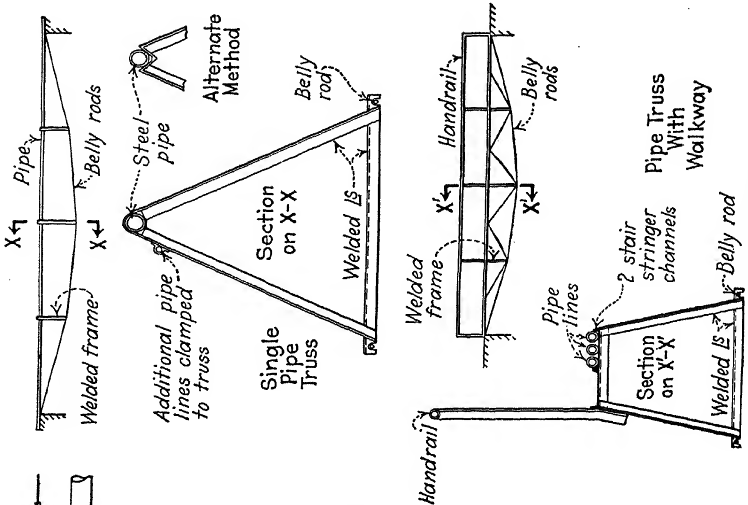

FIG. 26.—Pipe-truss details.

equal twenty-five times the width. The channels may be welded or bolted together and the trussing welded solid underneath so that the span can be placed in one piece. Such a support is especially suitable for glass, hard-rubber, fused-silica, vitrified-tile or silicon-iron piping.

For single lines of large, heavy pipe, steel trusses fabricated specially are usually required. A particular feature of such trusses should be to allow the piping to be swung up into place with the least work; in other words, the piping should be set between or below the trusses rather than above them. When single lines of steel pipe 2 in. and larger are used, then an especially economical form of bracing may be arranged whereby the pipe itself forms the top member of a truss frame (see Figs. 25 and 26).

Process Steam Piping.—In refineries, power plants and many processing plants, designers are continually faced with the problem of connecting the apparatus with pipes of the proper capacity and pressure. Often, long after the piping thus designed has been built and is in actual operation, similar additional problems continue to be a regular part of the work.

Steam is delivered from power plants at pressures above 150 lb. gage, but practically all chemical plant processes operate at 15 lb. or less, except where specially constructed equipment may be necessary, such as thick cast iron to withstand corrosion. Black-iron (steel) pipe is ordinarily used for steam. When oil is the heat-transfer medium for high-temperature processing, equipment not especially constructed for high-pressure work can be used.

Steam Reducing and Regulating Valves.—Jacketed equipment of many kinds, for which the safe working pressure is 15 to 30 lb., is common in chemical plants. In order to bring steam down from the line pressure, a reducing valve is necessary. This is placed in the service line between the feed and the equipment. To assist in repairing a reducing valve, which often leaks or becomes unseated, a by-pass should always be made around the reducing valve (see Fig. 21). Such a by-pass is best provided with a globe valve to permit manual control of pressure if the reducing valve is out of service. In order that this can be accomplished, the reducing valve should have valves on both inlet and outlet sides, with the pressure gages beyond the by-pass connections. Valves

of all kinds leak, and such leaks, when the plant is not operating, would permit the building up of pressure in the service lines and equipment; such conditions might lead to destructive consequences should the equipment be unable to withstand the pressure. Therefore, service lines close to the equipment should be provided with safety pop valves adjusted to safe pressures in accordance with the equipment in use. A popping valve, hence, indicates leakage at the reducing or shutoff valves and the need for repair.

Selection of Steam-pipe Size.—It is quite important in the design of piping connecting various pieces of apparatus to select a pipe size large enough to deliver the required quantity of steam, allowing for friction loss of pressure. On the other hand, the size must not be so large as to make the first cost of the installation unnecessarily great. At the same time a pipe size must be selected which can be regularly obtained from the pipe-manufacturer's stock. When too large a pipe is selected, the incidental valves and fittings are also larger than needed, adding both to first cost and to the general expense of maintenance. In large installations, epecially those of an intricate nature, the difference in cost caused by the selection of but a single size larger pipe than needed may well represent a staggering sum.

Although this subject in its entirety is necessarily of a complex nature, there are many useful relations and short cuts that can be put to good practical use. In commercial practice the designer usually does not have time to derive his own formulas, nor can he usually spare time to make tests or trace back through extensive mathematical transpositions for proofs. Instead he must select a standard formula, apply it to the work at hand and check the results against those of some other well-known formula. Or, if tables are available, he will use such of them as will apply to the problem in question (see Fig. 27).

Determination of Steam-pipe Sizes.—The velocity chart (Fig. 27) is a great timesaver in calculating velocities, discharge and size of pipe required for given conditions of flow.

Example.—Allowing a velocity of 5,000 ft. per minute, what size of pipe is necessary to deliver 8,000 lb. of steam per hour at 120 lb. gage?

Solution.—Trace the 5,000-ft. velocity line to 120 lb. gage on the chart. From the intersection, follow horizontally to 8,000 lb. of steam per hour. Read the nearest size of pipe, *viz.*, 4 in.

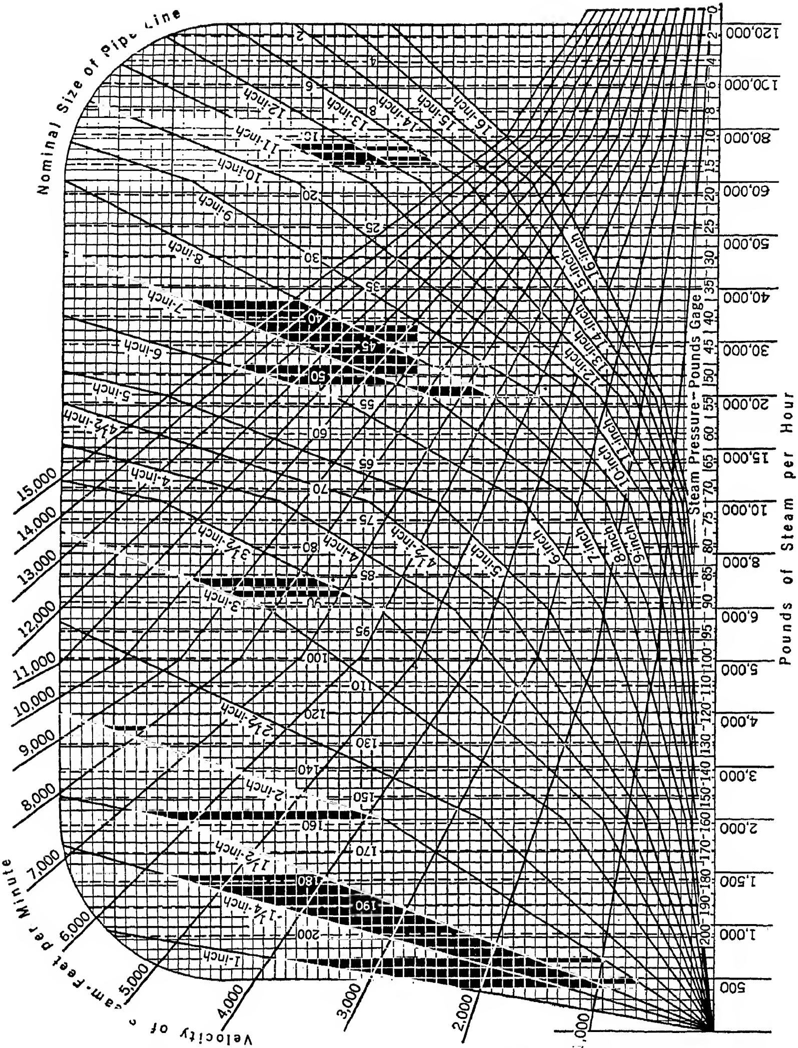

FIG. 27.—Steam velocity chart. (*After J. M. Spitzglass, Republic Flow Meters Company, Chicago.*)

For a smaller range of capacities and steam pressures Table 9 enables one to make a ready selection of pipe sizes.

The probable drop or loss of pressure is dependent upon the velocity of flow, length of line, number of turns in fittings or valves, and the covering of the pipes.

TABLE 9.—STEAM SUPPLY PIPE SIZES[1]

Capacity, pounds of steam per hour	Gage pressure, pounds per square inch							
	0	1	2	5	50	100	150	200
100	2½	2	2	1½	1	1	1	1
150	3	2½	2½	2	1¼	1	1	1
200	3	3	2½	2	1¼	1¼	1	1
300	3½	3	3	2½	1½	1¼	1¼	1¼
400	4	3½	3	3	2	1½	1¼	1¼
500	5	4	3½	3	2	1½	1½	1¼
750	5	5	4	3½	2½	2	2	1½
1,000	6	5	5	3½	2½	2	2	2
1,250	6	6	5	4	3	2½	2	2
1,500	8	6	5	5	3	2½	2½	2
2,000	8	8	6	5	3	3	2½	2½
3,000	10	8	8	6	4	3	3	3
4,000	10	10	8	6	4	3½	3½	3
5,000	12	10	8	8	5	4	3½	3½
6,000	12	10	10	8	5	4	4	3½
8,000		12	10	8	6	5	4	4
10,000		12	10	10	8	5	5	4
15,000			12	10	8	6	5	5
20,000				12	8	8	6	6
30,000					12	8	8	6
50,000					12	8	8	8

RECOMMENDED PRESSURE DROPS PER 100 FEET ON WHICH THE ABOVE TABLE IS BASED

Pounds per square inch	0	1	2	5	50	100	150	200
Pressure drop in pounds per 100 ft.	0.031	0.062	0.125	0.25	0.75	1.00	1.25	1.50

NOTE: The pipe sizes in the above table are sufficient to take care of heating-up load.

[1] Carrier Corporation.

In every steam line there must be a difference in pressure between the inlet and outlet or there could be no flow, and this difference is increased by friction and radiation. In power-plant work a steam velocity of 4,000 to 6,000 ft. per minute may be employed in properly covered pipe 6 in. in diameter or larger.

Saturated Steam.—Steam in the presence of the water from which it is generated is called *saturated steam;* it has the same temperature as the water, and can have only one pressure and one density at any given temperature, for the three have a fixed relation to each other. The properties of saturated steam will be found in most general handbooks. (See Table VIII, Appendix A, and Perry's "Chemical Engineers' Handbook," pp. 2437–2441.)

Superheated Steam.—Superheated steam has a higher temperature than saturated steam at the same pressure, and it is produced by adding heat to saturated steam in a separate vessel called a *superheater.* It is independent of pressure, since at any pressure the steam may have any desired temperature above its saturation temperature. In practice the superheater is an extension of the steam space of the boiler, with which it is in open communication, and the pressure of the steam in the superheater is practically the boiler pressure.

The advantage to be gained by superheating does not lie in increased thermodynamic efficiency. Rather, the economy that results from its application comes from the reduction of internal thermal waste in the engine, incident to cylinder condensation. The superheated steam must be reduced to the temperature of saturated steam at the given pressure before condensation can take place. The saving resulting from the use of superheated steam is found to be greater with engines that are inefficient with saturated steam; small engines profit more by it than large engines, slow engines more than fast, and single engines more than multiple-expansion engines. The thermodynamic properties of superheated steam are shown in Fig. 28, which will be found useful in graphically determining the saturation temperature and enthalpy corresponding to any gage pressure 100 and 1,600 lb. per square inch. The properties of superheated steam are given in handbooks. (See Perry's "Chemical Engineers' Handbook," pp. 2441–2443.)

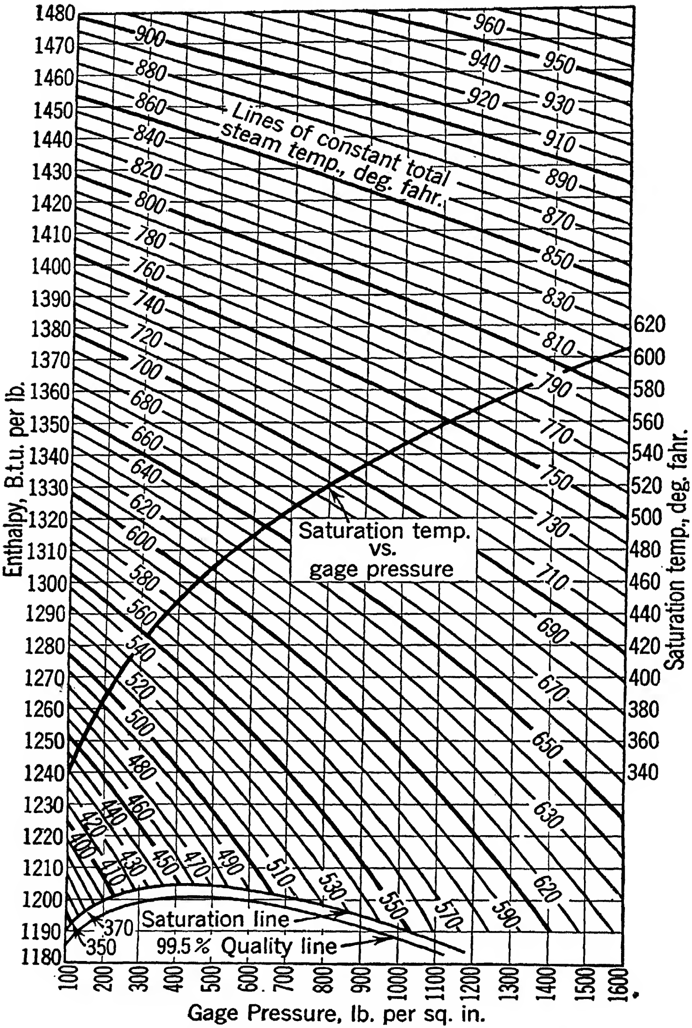

FIG. 28.—Pressure-temperature-enthalpy diagram for superheated steam. (*Printed by permission of Combustion Engineering Company, Inc.*)

PIPING INSULATION

The real object of insulation is to prevent the flow of heat to the outside surrounding air from a boiler, apparatus or pipe in which it may be generated, stored or conveyed, or to prevent the flow of heat from the outside to fluids or solids that should be kept cool or at low temperatures. The flow of heat from the fluid in a bare or insulated pipe to the outside surrounding air is measured by the number of heat units that flow through the walls of the pipe or insulation, or both, and is usually expressed as the number of B.t.u. that flow through an area of 1 sq. ft. in 1 hr. (B.t.u. per square foot per hour). The rate of flow through a certain thickness and at a certain difference in temperature determines the conductivity of the material through which the heat flows. A smaller number of heat units flows through a

TABLE 10.—85 PER CENT MAGNESIA INSULATION[1]

Steam pressure or condition	Temperature, °F.	Thickness of insulation, inches		
		Pipes, larger than 4 in.	Pipes, 2 to 4 in.	Pipes, smaller than 2 in.
Hot water	....	Std.	Std.	Std.
0–25 lb	212–266	Std.	Std.	Std.
25–100 lb	267–337	1½	Std.	Std.
100–200 lb	338–387	2	1½	Std.
Low superheat	388–499	Dbl. std.	2	1½
Superheat	500–600	3	Dbl. std.	1½
High superheat	600–700	2	1½	1½
Very high superheat	700–800	2	2	2
ASBESTO-SPONGE FELTED INSULATION[1]				
Hot water	....	1	1	1
0–25 lb	212–266	1	1	1
25–100 lb	267–337	1½	1	1
100–200 lb	338–387	2	1½	1
Low superheat	388–499	2½	2	1½
Superheat	500–600	3	2½	2
High superheat	600–700	3½	3	2
Very high superheat	700–800	3½	3	2

[1] Johns-Manville, New York.

given thickness of a material with a low conductivity than through one with a high conductivity.[1]

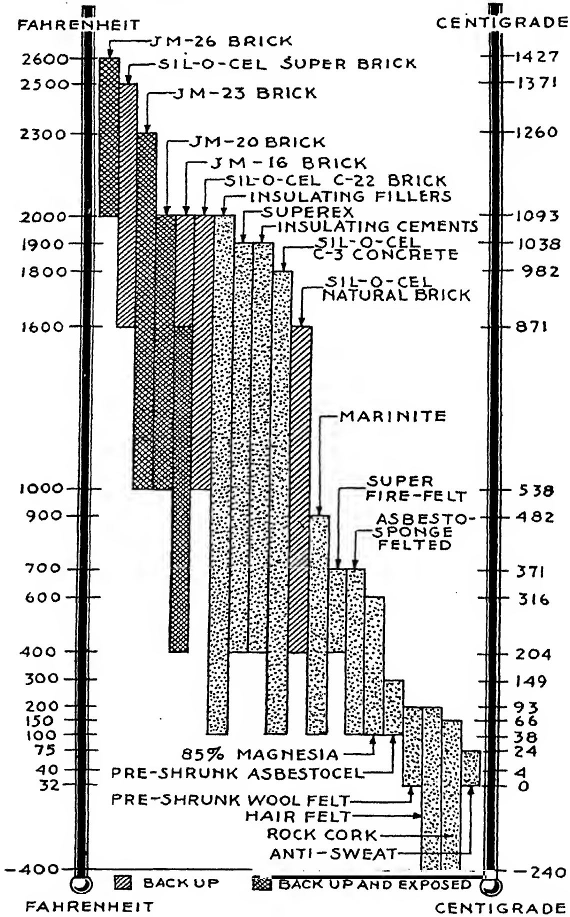

FIG. 29.—Insulation temperature limits. (*Courtesy of Johns-Manville, New York.*)

The efficiency of an insulating material is expressed by a percentage which is the per cent saving that would be effected

[1] Thermal Insulation Symposium, *Ind. Eng. Chem.*, **31**, 819–838 (1939).

by insulating a pipe with that material, over what would be lost if the pipe were left bare or uninsulated. The efficiency percentage is obtained by subtracting the heat loss of the insulated pipe from the heat loss of the uninsulated or bare pipe and dividing the difference by the heat loss from the bare pipe.

The following kinds of insulation are available in forms suitable for insulating pipes conveying heated fluids: Asbesto-sponge felted, super Fire-felt, Asbestocel, 85 per cent magnesia, wool felt, hair felt, insulating tape and special compositions. Insulating materials especially suited for use in cold work are also available. The insulation that should be selected for a particular application depends on the requirements of the individual job. In general, all pipes, fittings and flanges at temperatures below 600°F., except small fittings that are insulated with a special cement, should be insulated with Asbesto-sponge felted or 85 per cent magnesia, to the thicknesses given in Table 10. Asbesto-sponge felted insulation may be used, where service conditions warrant, up to 800°F. Proper materials for insulating pipes over the entire range of industrial temperatures are shown in Fig. 29.

Application of Pipe Insulation.—Sectional insulation is applied to a pipe with joints tightly butted and pointed up. Each section of insulation is wired to the pipe with not less than three loops of 16-gage annealed iron wire on pipe up to and including 6 in., and with not less than four loops for larger pipe sizes. All Asbesto-sponge felted insulation 2 in. and greater in thickness, 85 per cent magnesia of 3 in. and double standard in thickness, and combination insulation, should be applied in two layers with both circumferential and horizontal joints staggered, and with each layer securely wired in place as previously described. The insulation on bends should be given a thin finishing coat of cement to present a smooth, even surface. Insulation of flanges and fittings over 4 in. in diameter should be the same as the insulation on the line, surfaced with ½ in. of cement applied in two layers, the first coat being left to dry with a rough surface before the application of the smooth finishing coat. Canvas is stretched tightly over the cement and pasted neatly. On lines under 4 in., the fittings and flanges are insulated entirely with cement to the same thickness as the adjacent insulation. Outdoors, the flanges and fittings are waterproofed with Insulkote or a similar preparation, applied in place of the second coat of

cement, the canvas being omitted. All insulation on piping indoors should be finished with an extra jacket of 8-oz. canvas, sewed on over rosin-sized paper or asbestos paper and, if desired, sized with glue and painted with two coats of lead and oil paint. All insulation on piping outdoors, or exposed to the weather, should be protected with a waterproof jacket, the canvas being omitted. Pipe insulation located close to the ground or where there is possibility of mechanical injury should be protected with a metal jacket.

Weatherproof and Fire-resisting Pipe-insulation Jackets.—For outdoor lines, particularly those of some length, the most satisfactory insulation is Asbesto-sponge felted with an integral, waterproof jacket. Asbesto-sponge felted not only has high insulation value but also, owing to its construction, is not damaged by fall or blow and maintains its efficiency on hot lines over a long period of time. The integral jacket provides complete weather protection and obviates the labor of a separate application. Where insulation other than Asbesto-sponge felted with integral waterproof jacket is used, the best weather protection for insulated pipe lines out of doors consists of a waterproof asbestos jacket with all joints lapped at least 3 in. and all horizontal laps located on the side of the pipe, turned down to shed rain. Rings of heavy copperweld wire are applied on 4-in. centers to hold the jacket in place over the insulation. Where the insulation may be subjected to rough usage, a suitable metal jacket may be substituted for the weatherproof jacket. Where exposed to fire hazard only, it is good practice to apply an asbestos fire-retarding jacket. In such cases the application of asphalt-saturated roofing jackets is inadvisable, since flame may be carried along exposed piping when a fire occurs adjacent to lines so protected. The fire-retarding jacket consists of one sheet of asphalt-saturated asbestos felt over which is cemented an unsaturated felt. It will not drip asphalt, carry flame or support combustion.

CHAPTER V

PUMPS AND PUMPING

Pumps are used in chemical plants for a great number of purposes in transferring liquids, colloidal solutions or solids suspended in gases or liquids from one point to another. Pump transportation covers both long and short distances, horizontal and vertical, under pressure heads ranging from subatmospheric to very high pressures. Pumps are also used to produce both high and low pressures in equipment to aid physical or chemical processing reactions. Several excellent treatises on liquid handling and its data have been published by manufacturers of liquid- and gas-handling equipment. They contain not only descriptions of the equipment, its principles and its operation but also the necessary detailed information on capacities, dimensions and other pertinent data. This branch of equipment production is highly developed, and excellent sources of information are available.[1]

Classification.—A classification[2] of the types of pump at present on the American equipment market is given below:

A. Air motivation.
- 1. Jet pumps.
  - *a.* Steam jets.
  - *b.* Jet exhausters.
  - *c.* Jet compressors.
  - *d.* Siphons.
- 2. Air lifts.
- 3. Acid eggs, montejus, blow cases.
- 4. Barometric legs.

[1] Perry, John H., "Chemical Engineers' Handbook," 2d ed., sec. 20, McGraw-Hill Book Company, Inc., New York, 1941; Marks, L. S., "Mechanical Engineers' Handbook," 4th ed., pp. 1883–1907; McGraw-Hill Book Company, Inc., New York, 1941.

[2] Cuno, C. W., *Ind. Eng. Chem.*, **24**, 1109 (1932).

B. Reciprocating pumps or positive-displacement pumps with valve action.
   1. Piston pumps.
   2. Plunger pumps.
   3. Diaphragm pumps.

C. Rotary pumps, rotary movement, no valves.
   1. Centrifugal pumps, open or closed impeller, volute or turbine.
   2. Gear pumps.
   3. Screw pumps.
   4. Sliding-vane pumps.
   5. Cycloidal pumps.
   6. Blowers.
   7. Fans.

A. AIR MOTIVATION

Jet Pumps.—The jet pump is designed to employ a jet of water, steam or a gas as the operating medium, which flows rapidly through an expanding nozzle and discharges into the throat of a venturi. Here it gains velocity head at the expense of pressure head, producing a powerful suction and entraining gas, air or vapors that are drawn in around the jet from the vessel to be exhausted. As the moving fluid and entrained vapors expand through the venturi outlet, they are again compressed sufficiently to effect a discharge from the system.

Steam-jet Exhausters and Compressors.—Steam-jet exhausters, "evactors" and compressors are built to operate at moderately high vacuum and pressure. Live steam issues from the nozzle at high velocity (about 2,800 ft. per second). These exhausters are made in both the single-stage single-nozzle and multiple-nozzle types. In the latter type the steam issues from several jets into the throat of the venturi. The multinozzle arrangement gives maximum jet surface for entrainment of air and vapors and produces maximum compression so that the air and vapors may be discharged at atmospheric pressure or slightly above, even when the exhauster is maintaining high vacuum at the suction end. Such exhausters are used primarily for compressing air or gases, pumping air, evacuating closed vessels such as evaporators, crystallizers and jet refrigerating systems, and for priming pumps or siphon systems. When two or more jet exhausters are used in series, multiple-stage operation is attained.

Water-jet Exhausters and Compressors.—There are many instances in which neither steam nor compressed air is available

for vacuum-pump work, and there are many processes where the presence of steam, due to its heating action, would be objectionable. For such places the water-jet exhauster can be recommended. The nozzle is fitted with a spiral which gives the water a rotating motion. The capacities can be varied through wide limits by increasing or decreasing the water pressure. At 40 lb. pressure the water capacities vary from 5 to 700 gal. per minute.

Steam-jet Siphon Ejectors.—Steam-jet siphons are liquid pumps designed on the jet principle, using live steam instead of air as the operating medium. They are recommended for pumping water or other liquids in all instances where dilution with water is not objectionable, where durability, low cost and simplicity of manipulation are of primary importance, or where an increase in the temperature of the liquid is desired. Since the condensation of the steam used as the operating medium increases the temperature of the water or other liquid that is being handled, the heating of the liquid may be considered a costless operation. Or, if heating the liquid is the more important of the two operations, the pumping may be considered costless.

Steam-jet siphons are frequently used for emptying carboys, tank cars and other containers, and for transportation or transfer of chemicals from one tank to another. They are used for pumping out sumps or pits filled by leaks or drainage, for agitating liquids and for removing mother liquor from crystals and waste liquors from sediment. They are equally useful for moving sewage, mine waters, water containing solids, etc. For such installations, the siphon must be made of a material that will withstand the chemical action of the liquid handled.

Sizes and capacities of siphons are listed by manufacturers according to lift and elevation, size of connections, and pressure of steam used. The quantity of liquid moved also depends upon the temperature of the liquid. Under average conditions, the liquid can be elevated 50 ft. Where it is necessary to overcome elevations of more than 100 ft. and at the same time maintain suction, specially designed siphons are required or two pumps may be used in series. Montgomery gives a table in Perry's "Chemical Engineers' Handbook," p. 2263, on a steam-operated siphon, showing the limits of suction and capacities that are possible with various steam pressures and for various

sizes of the steam-, suction- and delivery-pipe connections. Standard siphons with moderate suction will handle liquids at fairly high temperatures. If the siphon is submerged, or the liquid flows to it by gravity, water temperatures as high as 140°F. can be handled. Usually an ejector or siphon will elevate twice as high as it will lift; also, liquids may be elevated approximately 1 ft. for each pound of steam pressure.

Air Lifts.—The air-lift pumping system is a method of lifting water or other fluids by means of compressed air without the use of valves, cylinders, plungers or other mechanisms. A discharge or eduction pipe extends from a distance below the level of the water to a point of discharge, and an air pipe opening at the lower end of the discharge pipe forces a mixture of air and liquid up through the discharge pipe. Air lifts are used in dredging, in lifting acids, alkalies, corrosive liquids and liquids of high specific gravity, and in agitating chemicals. They are employed in connection with irrigating systems, in municipal water works, sewerage works, refrigerating plants, cold-storage plants, packing-houses, dye and textile works, etc.

Capacities of air lifts for various sizes of air inlet, casing and central air pipe are compiled in Perry's "Chemical Engineers' Handbook," p. 2262.

Acid Eggs.—The acid egg, common in sulfuric acid plants, consists of a closed vessel with inlet and discharge lines and an air connection. In the manually operated type, air is admitted through the hand regulation of the valve to force the liquid out through the discharge pipe. In the automatic type the flow of air is controlled by a float valve within the vessel. Both types contain check valves in both inlet and discharge pipes, and both are intermittent in operation. The elevation attained depends upon the air pressure. Acid eggs, also called *blow cases* and *montejus*, are inexpensive, easy to operate, and give little mechanical trouble; however, their efficiencies are low.

The Barometric Leg.—The barometric leg pump is seldom operated by itself but requires the use of an auxiliary pump to remove fixed gases that accumulate from the liberation of the dissolved gases in the solution. The leg is longer than the Torricellian leg, *i.e.*, over 34 ft., and empties into an open well. Its principal application is in removing the condensing water

and condensate from jet condensers employed to produce a vacuum in evaporators, vacuum pans, vacuum crystallizers and steam-jet refrigeration equipment.

B. RECIPROCATING PUMPS

The reciprocating pump is the oldest and best known form of pump. The delivery of liquid is effected by the displacement of a piston or plunger. The flow of liquid is intermittent, owing to reversal in the movement of the piston. All reciprocating pumps use valves that must be properly selected for the different services. Owing to incompressibility of fluids, the speed of reciprocating pumps is very limited.

As a general rule, reciprocating pumps are now used for comparatively small capacities against high heads. Ordinarily they will operate on higher suction lifts and will handle fluids of higher viscous consistency than centrifugal pumps. Since they will keep their prime, they are particularly suitable for installations that require automatic control.

Classification of Piston and Plunger Pumps.—With reciprocating pumps the capacity depends on the displacement of the plunger and the speed with which it is operated. By increasing the speed, the capacity may be changed without affecting the head except for an increased friction in the pipes on account of the increased velocity of the liquid. The general classification of these pumps can be summarized as follows:

A. Piston.
- 1. Location of valves.
  - *a*. Submerged.
  - *b*. Straightway.
- 2. Service demands.
  - *a*. Trade.
  - *b*. Pressure.
- 3. Type of valves.
  - *a*. Pot valves.
  - *b*. Deck valves.
  - *c*. Mechanically operated valves.
  - *d*. Ball valves.
  - *e*. Flap valves.
- 4. Action of water cylinder.
  - *a*. Single acting.
  - *b*. Double acting.

5. Number of water cylinders on a single drive mechanism.
    a. Simplex.
    b. Duplex.
    c. Triplex.
6. Motive power.
    a. Steam pump.
    b. Power pumps.
        i. Direct acting.
        ii. Crank and flywheel.
            a. Belt.
            b. Electric motor.
            c. Water wheel.

B. Plunger.
    (1) to (6) above.
    7. Inside packed.
    8. Outside packed.
        a. Center packed.
        b. End packed.

Trade and Pressure Pumps.—Pumping water and other liquids under heavy pressure presents a problem differing in many respects from that involved in ordinary work where the pressures are comparatively light. Heavy pumping work demands not only greater strength in the parts of the machinery employed but also radical changes in general design. The best modern practice places the deciding line between the *trade* pump and the *pressure* pump at about 200 lb. per square inch working pressure. In boiler-feed work the point of departure from the common trade pump is often lower, many engineers preferring a pot-valve pressure pump for boiler plants carrying 150 lb. pressure and above. The principal modifications in design which distinguish the so-called "pressure pump" consist in the subdivision of the water end castings, the elimination of screwed valve seats and in the type of water valve and method of guiding it. Also, nearly all patterns of pressure pumps have outside end-packed water plungers, thus keeping the piston rods out of the water cylinders.

The variety of reciprocating pumps is indicated by the specific applications for which pumps are used. Among the variety of pumps available can be included deep-well, boiler-feed, condensation, dry-vacuum, wet-vacuum, compound, filter-press, hydraulic-press, creamery, milk, oil, fuel-oil, lime and magma pumps.

Some data on the capacity of simplex, duplex and triplex pumps are found in Perry's "Chemical Engineers' Handbook,"

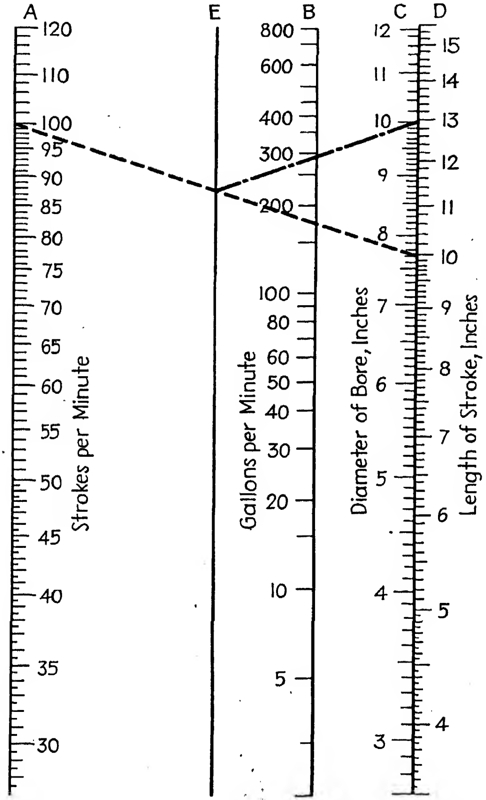

FIG. 30.—Capacity of reciprocating pump. (*Courtesy of Economy Pumps Inc.*) This nomograph shows the capacity of a reciprocating pump operating without slip where the size and number of strokes is known.

Example: A pump of 10-in. bore, 10-in. stroke running 100 strokes per minute: Locating 100 on line *A* and 10-in. on line *D*, we draw a line between them; then, locating the intersection of this line with line *E* and locating 10 in. on line *C*, we draw a connecting line. Where this line crosses *B* we have the delivery, or 290 gal. per minute, of the reciprocating pump.

pp. 2256–2258. Figure 30 shows the capacity of reciprocating pumps operating without slip.

Diaphragm Pumps.—The diaphragm pump is the only pump that is immune from clogging and abrasive wear in handling pulps, sludges and other nonhomogeneous materials. The suction type is an open pump and is not designed to work against pressure heads. Diaphragm pumps have also been developed to fill the recognized need in the chemical, metallurgical and sanitary fields for a pump that has all the wearing and operating advantages of the open-suction type, with the additional property of forcing pulps and sludges to high elevations, or through horizontal pipes at long distances. Capacities of diaphragm pumps can be varied by changing the speed, length and diameter of the piston diaphragm and cylinder. Capacities are given in Perry's "Chemical Engineers' Handbook," p. 2265.

C. ROTARY PUMPS

Centrifugal Pumps.[1]—The development of the modern centrifugal pump has been made possible by the high speeds of electric motors and steam turbines. The flow produced by a centrifugal pump is free from pulsations, and its advantages are numerous. Such pumps are compact, rugged, dependable and simple to operate. They may be manually operated, or employ combined manual and automatic operation. Auxiliary stand-by gas-engine drives may be used with either turbine or motor drive, assuring constant service. Centrifugal pumps will deliver a steady flow of water, free from water hammer which sets up injurious vibrations in sprinkler and other lines. They will operate against a closed discharge without building up dangerous pressures and will deliver an increased capacity at reduced heads. The centrifugal pump has no valves to stick or dry up, no reciprocating parts that must constantly be kept in motion to prevent corrosion, and no close metal-to-metal fits. Centrifugal pumps are more dependable and cost less to install than reciprocating types.

The centrifugal pump must be primed each time when started. It will not develop so high a suction lift as the reciprocating pump and it shows a decreased capacity when handling viscous liquids.

There is a practical limit in head beyond which it is not economical to use a *single-stage* centrifugal pump. For the highest

[1] Marks, L. S., "Mechanical Engineers' Handbook," 4th ed., pp. 1893–1907, McGraw-Hill Book Company, Inc., New York, 1941.

heads, either a very high rotative speed or a large diameter of impeller must be used. Both of these lead to high mechanical stresses and to lowered efficiency, owing primarily to disk friction and leakage losses. Disk friction increases very rapidly with increased speed or impeller diameter, the horsepower thus lost varying approximately with the cube of the speed and the fifth power of the diameter. Thus, a higher speed and smaller diameter would give less disk friction for the same head. However, leakage loss, resulting from liquid passing back from the case to the suction through clearance spaces, increases with the smaller diameter and shorter leakage path. At high heads, with the greater pressure difference between case and suction, the leakage loss is an important item. As a result of these effects, the efficiency of a high-head pump is likely to be comparatively low.

Although a single-stage pump has delivered at a head of 1,000 ft., practical designs limit the head to not over 300 ft. per impeller. For the higher heads, two or more impellers are connected in series, the discharge from one impeller being the suction of the next. The total head is the head of each impeller multiplied by the number of impellers. For the sake of economy such an arrangement is built in one case and is known as a *multistage* pump, each impeller constituting a stage. Ordinarily not more than six stages can be built in one pump casing on account of the length of shaft. Room for a large shaft is difficult to get because of the space required to lead the liquid into the eye of the impeller, and a long shaft must be rigid in order to prevent undue vibration. Where more than six stages are required, the usual practice is to split the requirements into two pumps placed on both ends of the motor shaft, and back to back to neutralize end thrust by having one pump oppose the thrust of the other.

As the capacity of a centrifugal pump varies with the speed, and the head varies with the square of the speed, it is important that the pump be operated at the proper rate. No installation should be made without checking speed, capacity, horsepower, etc., with the tables given for the pump by its manufacturer. (See Perry's "Chemical Engineers' Handbook," pp. 2245–2251.) Montgomery states that:

> The only method for selecting centrifugal pumps that assures procurement of a suitable unit is to assemble complete data as to conditions under which the pump must operate, and then purchase, upon guarantee, after consultation with several manufacturers of this type of equipment.

The usual type of Information Requested sheet sent out by manufacturers of centrifugal pumps is similar to the one reproduced in Table 11. Table 12 gives typical capacity data for centrifugal water pumps.

The various practical methods used to prime centrifugal pumps may be divided into five classes, and each has its field or

TABLE 11.—DOWNIE CENTRIFUGAL PUMPS

Information Required for Estimates

Due to the conditions under which centrifugal pumping machinery is required to operate, varying considerably, the intending purchaser should give the information requested below in order that accurate recommendations and quotations may be made promptly by mail.

PUMP

1. Number of pumps required................
2. Capacity of each pump................gal. per minute.
3. Character of liquid................salt, brine, fresh, clear or gritty.
4. Specific gravity................
5. If liquid is warm, give temperature................
6. If liquid contains solid matter, give character and approximate size larger pieces................
7. Service, continuous or intermittent................
8. Total head in ft. or lb. pressure, including vertical suction and discharge lift (or equivalent) and frictional losses through pipes, bends and valves
9. Suction lift (if any)................ft. or pressure at pump inlet (if any)................ft.
10. Length and diameter discharge pipe................
11. Number of bends in discharge pipe, and state whether 90, 45, or 22½ deg................
12. Length and diameter suction pipe................
13. Number of bends in suction pipe, and state whether 90, 45 or 22½ deg.

DRIVING POWER

14. Belted—State speed motor or engine................diameter of pulley................
15. Direct connection electric motor—give characteristics of available current. Direct current, voltage................Alternating current, voltage................cycles................phase................
16. Direct connection steam engine—steam pressure................condensing (back pressure)................non-condensing................
17. Direct connection combustion engine—gas................gasoline................kerosene................crude oil................
18. Driving power—whether to include in quotation or will be furnished by purchaser................

To insure satisfactory operation of a centrifugal pumping unit it is very important to predetermine, as closely as possible, the total head against which the pump is to operate. Therefore, a careful check should be made by the intending purchaser of the vertical distance the pump will be required to operate, and give careful consideration to the possible frictional losses through the suction and discharge piping. If the intending purchaser is unable to determine this definitely, it is then a good plan to submit a rough sketch of the pipe lines indicating the diameters, length, number of bends, and character of same, which will enable us to make an accurate estimate.

range of usefulness. Each method is also limited, in varying degree, by local pumping conditions and cost considerations.

1. Placing the pump below the source of supply, so that the water flows to the pump by gravity, is one of the most direct ways of ensuring that the pump will always be primed. This arrangement, however, may be unnecessarily expensive. It may cost too much to dig a pit for the pump, erect a wall to dam back the water, or make other provisions for getting the pump placed below the water level in the supply tank or basin. Then too, it is often necessary to guard against air accumulating in the pump casing even when the water flows to the pump.

2. A check valve, or foot valve, may be placed at the end of the intake pipe, the arrangement being such that the valve traps the water in the pump when the unit is shut down, thus keeping the pump primed. The foot valve may leak, causing the pump to lose its prime, especially if there is any considerable amount of

TABLE 12.—CENTRIFUGAL WATER-PUMP CAPACITIES

Single-stage, double-suction
Ball-bearing, direct-connected
Maximum gallons per minute

Motor horse-power	Head, feet 20	50	100	200
1	150	.....	.....	.....
2	250	100	.....	.....
3	450	175	50	.....
5	800	275	125	50
7½	1,100	450	225	75
10	1,250	700	300	125
15	1,500	900	450	200
20	1,750	1,250	600	275
25	.....	1,750	800	350
30	.....	.....	1,000	450
40	.....	2,000	1,250	600
50	.....	.....	1,750	800
60	.....	.....	2,000	900
75	.....	.....	.....	1,250
100	.....	.....	.....	1,500

Capacities are for 60-cycle motor speeds.

Single-stage, single-suction
Plain bearing, belt-driven
Maximum gallons per minute

Motor horse-power	Head, feet 10	20	50	80
0.5	30	.....	...	...
1.0	100	45	...	...
1.5	125	115	10	...
2	220	160	25	...
3	330	175	30	...
5	750	400	160	...
7½	1,200	640	240	...
10	.....	1,000	320	200
15	.....	1,500	450	300
20	.....	1,700	800	350

NOTE.—Irregularities which may be detected in these tables are common to all manufacturers, but in different items.

solid matter in the water. There is also danger of the foot valve causing water hammer in the discharge pipe and pump casing, often resulting in a broken pump. In general, this system is limited to pumps handling clear water and operating under a low head with a short discharge pipe.

3. An ejector provides one of the simplest and least expensive means of priming a suction-lift centrifugal pump. Its use is recommended wherever steam, air or water under pressure is available for actuating the device.

4. Small pumps can often be primed with an inexpensive, hand-operated vacuum pump, thus doing away with the necessity of a foot valve and at the same time keeping down the cost of priming equipment. The use of a vacuum pump is generally the most satisfactory priming method for large centrifugal pumps. When a dry vacuum pump and vacuum breaker are used, the action is positive and simple, and there is almost no danger of the operator's starting the pumping unit before it is fully primed.

5. An elevated tank serves as an inexpensive priming device, the principal drawback being the need to keep the tank always full. The elevated-tank principle has been incorporated in a self-priming pump, using a two-tank set constructed into the centrifugal-pump casing. One tank connects with the suction and the other with the discharge line of the pump.

Gear Pumps.—One of the most common types of positive rotary pump employs two meshing gears within a close-fitting case. Liquid is trapped by the gear teeth and carried from intake to discharge. The meshing of the gears seals the pump against backflow. For pumps with capacities from 4 to 850 gal. per minute, at 60 lb. per square inch head, a cost range between $95 and $800 prevails, not including the motor.

Screw Pumps.—The screw pump is a special type of gear pump, employing two meshing screws in a figure-of-eight casing. Such pumps are built to handle any liquid or semiliquid that will flow through a suction pipe, such as molasses, brine, water, heavy and light grease, oils and acid sludges. They are built in capacities ranging from 2 to 4,200 gal. per minute, against pressures up to 1,000 lb., or more, per square inch. Such pumps have been used for extruding cellulose nitrate solutions at pressures as high as 2,500 lb.

Sliding-vane Pumps.—A special design of sliding-vane pump embodies an eccentric casing. Either the rotor and shaft are eccentric to the casing, or the casing is elliptical in shape. In the sliding-vane or ring types, the rotor carries the slides in and out because they rest on a stationary ring.

Because of their simplicity of design and ruggedness, most rotary gear and vane pumps are particularly adapted to the pumping of liquids more viscous than water, such as molasses, tar, soap and oil. Such thick, slow-flowing liquids cannot always be handled satisfactorily by either piston or centrifugal pumps. Such rotary pumps usually depend for their lubrication on the material being pumped, and, if long life is desired, should not be used for liquids that do not have some lubricating qualities. They are built with close clearances and consequently should not be used for handling liquids containing grit or solids. (See Perry's "Chemical Engineers' Handbook," p. 2259.)

Cycloidal Pumps.—Cycloidal pumps consist of two close-fitting figure-of-eight impellers revolving in opposite directions on their parallel shafts in an elliptical casing, the liquid or gas being drawn into the pockets between the impellers and the casing, and delivered positively to the opening of the discharge. Like any gear or rotary pump, they can be used for liquids or gases, as either blowers, compressors or pumps, according to design.

The Nash Hytor is a type of double-elliptical pump for air and gases, the circular, vaned rotor revolving in an elliptical casing, forcing water or some other liquid to follow the outline of the casing and thus act as the piston, seal and valving mechanism. It ranges in capacity (expressed in cubic feet of free air per minute, referred to a 30-in. barometer and 50 per cent relative humidity, with 60°F. sealing water) between 6 and 4,400 cu. ft., over a pressure range of from 5 to 45 lb.; this is with motor speeds between 212 and 3,500 r.p.m. and horsepower requirements between 2 and 400. As a vacuum pump, expressed in cubic feet of free air per minute at specified vacuum, the pump delivers from 21 to 4,950 cu. ft. at vacuums between 5 and 27 in.; here the horsepower requirements are between 2 and 200.

Fans, Blowers, Exhausters, Compressors.—For the propulsion of air and gases types of pumps are used involving movements of volumes by not too close contact or seals. The fan is used for

moving large volumes of gases, depending upon the attainment of high velocity to produce the desired increased pressure, the rotating member not in airtight contact with the stationary part. The fan is of propellor style or of the multibladed squirrel-cage type. When used in multistage form these fans can deliver air at moderately high pressures.

PUMPING DESIGN

Location of Pumps.—The location of a pump in a chemical plant is of prime importance. If possible, pumps should handle the liquids in their least reactive condition, *viz.*, as water, pumping this to the levels where solutions can be made and the subsequent reaction equipment fed by gravity. There exist but few cases where only water need be handled; in most, the process will demand a certain amount of handling of corrosive solutions and solutions whose purity should be maintained. The choice of materials of construction then must be considered. When solutions are likely to contain abrasives, if it is possible to do so, pumps should be placed so as to avoid or materially reduce the handling of such solutions.

Materials of Construction.—The materials used in pump construction depend upon the service demanded. Although there do not exist all-purpose, corrosion-resisting materials, there are materials that have great resistance to specific corrosive reagents, and the knowledge of the chemical reactivity between various chemicals and chemical solutions, and materials of construction, is necessary in proper pump selection.

Glass, porcelain, enamel-lined and stoneware pumps have but limited application owing to the inability to withstand mechanical and severe thermal shock. The high silicon-iron alloys such as Duriron, Tantiron and Corrosiron are more applicable to severe mechanical shock than the materials mentioned above, but nonmachinability and the high cost of grinding these very hard and brittle materials restrict their application. Lead and lead alloys are applicable for pump materials but are limited to uses wherein lead does not enter into the reaction. Special hard lead, firmly adherent to a supporting outer shell of cast iron or other metal, has been adopted as practicable. Hard-rubber-lined, Pyrex and plastic pumps are also available and highly desirable for pumping hydrochloric acid.

Brasses and bronzes, iron-base alloys, nickel, Monel metal, magnesium alloys, hard rubber, plastics, tin, aluminum and like metals must be added to ordinary gray and white cast iron, as a few of the materials that can be used in pump construction. Practically any alloy or modern metal can be fabricated into pumps, and it remains only for the chemical engineer to stipulate the kind of solution he wishes to handle, or the kind of metal, and the pump manufacturer will attempt to construct a pump for the service demanded. (See Perry's "Chemical Engineers' Handbook," pp. 2099–2105, and Marks' "Mechanical Engineers' Handbook" p. 1884.)

According to Marks' Handbook (p. 1883, 4th ed.);

> The allowable stresses in pumps are lower than in most machinery owing to the shocks and water-hammer, and the tensile stresses in pounds per square inch may be taken as follows: Cast iron, 1,500 to 1,800; malleable iron, 3,000; steel castings plain, 8,000; complicated, 5,000; bronze (government metal), 3,000; Tobin bronze, 5,000; steel, 7,000; and forged steel, 10,000.

The materials to be used for pump parts vary with the chemicals handled (see Tables 40 and 41).

Drives for Pumps.—Following is a classification of drives for pumps for general service:

A. Direct drive.

This form of drive is particularly suited to high-speed machinery and is, therefore, limited almost entirely to centrifugal and certain rotary pumps.

1. Advantages.
    - *a*. Compact; requires minimum amount of floor space.
    - *b*. Simple; no intermediate mechanism necessary between pump and driver.
    - *c*. Quiet; no gears or other noisy mechanical devices.
    - *d*. Dependable; no intermediate mechanism to go wrong.
    - *e*. Adaptable; location independent of line shaft or other source of power.
    - *f*. Efficient; no power loss between pump and driver.
    - *g*. Low maintenance; no belts, gears or other mechanical devices demanding attention.
    - *h*. Low first cost; usually cheapest method of drive.
2. Disadvantages.
    - *a*. Not flexible; pump must operate at speed of driver.
    - *b*. Limited range; difficult to obtain variation of capacity and head when dependent on speed.

B. Belt drive.

Suitable for any type of pump and any source of power. Idlers permit short-coupled outfits and automatically take up belt stretch.

1. Advantages.
   - *a*. Flexible; practically any driver can be accommodated by proper ratio of pulley sizes.
   - *b*. Less breakage; in case pump is overloaded or jammed, belt will run off, thus protecting pump and driver from damage.
   - *c*. Wide performance range; variations of capacity and head conditions easily met by changing pulley ratios.
   - *d*. Adaptable; particularly suited to temporary installations; also for severe intermittent service.
2. Disadvantages.
   - *a*. Maintenance; under certain industrial conditions, or if exposed to the elements, belts wear, stretch, break and deteriorate rapidly.
   - *b*. Bulky; sometimes occupies valuable floor space, especially if an idler is used; factory laws require belt to be properly guarded.
   - *c*. Less efficient; belt slippage and power losses peculiar to this type of drive result in reduced efficiency and must be considered in cost of operation.

C. Gear drive.

Commonly used to adapt low-speed pumps (reciprocating and rotary) to high-speed drive units.

1. Advantages.
   - *a*. Compact; compares favorably with direct-driven unit; requires less space than belt drive.
   - *b*. Adaptable; location independent of line shaft or other source of power; greater speed reduction feasible than with belt drive.
2. Disadvantages.
   - *a*. Not flexible; a positive drive; a jammed pump means a burned-out motor, stalled engine or damaged pump.
   - *b*. Maintenance; careful alignment and proper lubrication necessary to long service.
   - *c*. Higher cost; gearing is expensive; must be made to suit individual requirements; must be guarded to protect operator.

D. Chain drive.

Used when belt or gear drive is not feasible or desirable.

1. Advantages.
   - *a*. Efficient; no slip or power loss as with belt.
   - *b*. Adaptable; wide range of speed combinations; fairly quiet in operation; particularly suited to installations where gears of large diameter would otherwise be necessary.
2. Disadvantages.
   - *a*. Higher cost; more expensive than belt or direct drive; must be guarded to protect the operator.

WATER SUPPLIES

Sources.—Water for industrial purposes can be obtained from one of two general sources, either the plant's own source or a municipal supply. If the demands for water are large, it is

TABLE 13

INTERNATIONAL FILTER CO.

WATER SOFTENING AND FILTRATION PLANTS
FOR MUNICIPAL, INDUSTRIAL AND DOMESTIC SUPPLIES
Works and General Office
333 West 25th Place
CHICAGO

> NOTE: The information requested on this data sheet is important—it enables us to understand your operating conditions and make the proper recommendations as to the type and size of water purification equipment needed to meet your requirements. This information will be held strictly confidential.
> As we build all types of water purification equipment our recommendations will be unprejudiced. Our reports, investigations and analyses are made without charge and place you under no obligation.

Date________________
From (Firm Name) ________________
Address________________ City__________ State__________
To whom should report be sent________________ Title__________

Please answer these questions

1. Source of water supply.
City water works?________; Private well?________; Do you obtain your private water supply from more than one well?________; Do you pump directly from a river?________; a lake?________; a pond?________. If the source of your water supply is not listed above explain it briefly________________

2. General information.
A. What is the maximum quantity of water used daily?________gallons.
B. What is the maximum quantity of water used in any one hour?________gallons.
C. How many hours continuously do you use the maximum quantity?________
D. How many times daily is the maximum run used?________
E. How many hours daily does your plant operate?________

3. Uses for softened water. (Check the ones that fit your case.)
Laundering ☐ Boiler Feed ☐ Processing Silks ☐ Woolens ☐ Cotton Goods ☐ Hotel ☐ Hospital ☐ Cooling Water for Gas-engine Jackets ☐ Describe briefly any use not listed above ________________

Please select from 4, 5, 6 or 7 the list that fits your case and answer all questions

4. If city supply is used answer these questions:

Waterworks office or City Engineer can give you these data.

A. What is the size of the street water main? ________inches.
B. How many service taps connect service pipe to street water main? ________ (Several small taps may have been made in street main and a corresponding number of small pipes lead out to form one connection to your service pipe.)
C. What is the size of each service tap? ________inches.
D. What is the size of each service tap? ________inches.
E. What is the distance from the street main to the point where service line enters your building? ________feet.
F. What is the size of your city water meter? ________inches.
G. What is the city water pressure? Normal________pounds. Maximum________pounds.
H. Approximately how far is it from the point where service line enters the building to the point where the water softener will be erected?________feet.

5. If you pump your water from a shallow well, river, lake or pond, answer these questions:
A. What type of pump do you use? Plunger or power?________; Centrifugal?________
B. If plunger or power pump give type________; bore________inches; stroke________inches; single or double acting________; maker's name________.
C. If centrifugal pump give number of stages________; size number________ maker's name________.
D. What is diameter of pump suction pipe? ________inches.
E. What is length of pump suction pipe? ________feet.
F. How many elbows in suction pipe? ________.

TABLE 13.—(*Continued*)

G. What is vertical distance between pump and surface of water while pump is in operation? ________feet.
H. What is length of discharge pipe from pump to storage tank? ________feet; diameter of pipe? ________inches; number of elbows in discharge line? ________.
I. What is speed of pump? ________R. P. M.
J. What is rated capacity of pump? ________gallons per minute.

6. If you pump water from a deep well with pump cylinder submerged, answer these questions:
A. What is bore? ________inches; stroke? ________inches; length of stroke? ________inches; number of up strokes per minute?________.
B. Is cylinder single or double acting? ________.
C. What is rated capacity? ________gallons per minute.
D. What is length of discharge pipe from pump to storage tank? ________feet; diameter of pipe? ________inches; number of elbows in discharge line? ________.
E. What is rated capacity of pump? ________gallons per minute.

7. If water is pumped to overhead storage tank before use, answer these questions:
A. What are the inside dimensions of storage tank? Diameter?________feet; height?________feet.
B. What is the distance from bottom of tank to floor upon which softener will be erected?________feet.
C. What is diameter of pipe that supplies tank? ________inches.

> Information as to the characteristics of the raw water supply must be known before recommendation can be made. The amount of hardness to be removed from the raw water governs the capacity between regenerations of any sized Exchange Type Softener. The information required can only be obtained by a reliable mineral analysis. If you have a recent analysis send us a copy; if not, send us sample in accordance with directions given. We will be pleased to ship container for taking sample if you will write us. This service is made without charge.

DIRECTIONS FOR SENDING SAMPLE OF WATER FOR ANALYSIS

[*The results of the analysis will be misleading unless the sample is carefully taken and fairly represents your water supply. Follow directions closely*]

QUANTITY: Not less than one-half gallon, preferably one gallon.
CONTAINER: Use only clean *glass* bottle. (Never use earthen jug or tin can.) Rinse bottle at least three times with water to be sampled.
TAKING SAMPLES: If sample is taken from tap or pump; let water run some time before sampling. If from stream or pond, avoid surface water, scum and sediment. Leave good sized air space below cork. Use new cork, stopper tightly and seal or wire on cork.
MARKING: Label each bottle plainly. Give name of sender and date when taken. Mark on *each* bottle the source of the water, that is, whether from well, pond, river, lake, etc.
Ship sample to Laboratories, International Filter Co., 333 West 25th Place, Chicago, Illinois

more economical for the industry to supply its own water. Such a supply may be obtained from drilled wells, rivers, dammed streams or other impounded supplies. Before a company enters upon any project, it must assure itself of a sufficiency of water for all industrial, sanitary and fire demands, both present and future. Data on maximum, minimum and average rainfall can be obtained from government agencies if surface water is to be impounded, or the data on stream flow of rivers can also be acquired likewise. If wells are to be relied on, geologists and practical well drillers should be consulted. A specimen inquiry sheet on a water supply is given in Table 13.

Drilled wells tap deep reserves. To lift this supply to the surface, centrifugal pumps, suction pumps, rotary pumps or air lifts are generally used. The air lift is quite economical and

trouble-free since it has no screens to clog or valves to leak. The moving parts of the motivating force, the air compressor, are all out of contact with the water and any grit borne by it. An additional advantage is that soluble ferrous iron is oxidized by the aeration process.

Pumping Water.—In pumping water to and in mills, two general types of pump are common: (1) triplex pumps, with high first cost, slow speed and high efficiency; and (2) centrifugal pumps, with low first cost, high speed and lower efficiency. The triplex pump at constant speed will deliver a definite quantity of water to any height within its limiting pressure, the power being proportional to the pressure at the pump. Efficiencies range from 70 to 80 per cent. Variation in speed varies the quantity directly, while efficiency remains practically constant over a wide range of speeds and pressures. These remarks apply to all power-driven piston and plunger pumps.

The centrifugal pump at constant speed will produce a very definite pressure at shutoff (no flow). As the valve is opened to permit flow, this pressure is reduced. Pressure varies as the square of the impeller speed, power as the cube of the speed, and quantity (theoretically) as the speed. Actually the last depends upon the conditions causing pressure. Efficiency varies from a low figure at shutoff (maximum pressure) and free delivery (zero pressure) to as high as 80 per cent at some delivery between these points.

Pumps.—If pumping from a river, pit or lake, the centrifugal pump is generally preferred, the selection of type being a matter of some moment. One of the inherent disadvantages of the centrifugal pump is its frequent need of priming, although self-priming pumps are available. A number of methods for priming centrifugal pumps are explained on pp. 77, 78. All water lines must be laid underground and below the frost line. In order to reduce renewals, cast iron is generally used for water mains buried underground. If either the distance to be pumped or the elevation of the terminal is too great for a single centrifugal pump, the judicious placement of booster pumps will serve. Reciprocating pumps are more efficient in their service for pumping to high elevations or against considerable friction, but they are rather inflexible and cause more or less pulsation of the water stream, which may be annoying.

Plumbing Codes.—The water supply of buildings, including heating equipment for water, the gas piping, the system of drainage and sewerage and the various fixtures connected therewith, are installed by the plumber in accordance with specifications prepared by the architect, based on municipal regulations or some standard code. These regulations are instituted as a measure for ensuring workmanship in accordance with approved health regulations. An investigation of various municipal codes will easily convince the chemical engineer of the importance of competent inspection of any sewerage and drainage setups necessary in his plant.

Towers.—The water tower is essential in the water system to act as a buffer in the line, to maintain a uniform head of water, to store water against temporary breakdowns in the plant, and for fire protection. Water towers are generally built to specification, but standard tanks are made in all parts of the country. Steel tanks for capacities of 25,000 to 1,000,000 gal. for high head range and up to 2,000,000 gal. for low head range are standard.

Although the head range between a full and an empty tank in the larger capacities may be excessive for some installations, in most cases the reserve storage capacity provided for fire protection will be enough to keep the ordinary head fluctuations within reasonable bounds. Table 14 gives data on Pittsburgh-Des Moines standard, hemispherical, elevated water tanks, or towers, for three- to four-panel towers and for 25,000 to 100,000 gal. capacities. Such tanks are ready for immediate shipment. Other sizes can be obtained on short notice.

Hemispherical-bottom tanks are designed with the most economical dimensions in various capacities, for ordinary requirements and for high head ranges.

When a low maximum head range is necessary ellipsoidal-bottom tanks are used. These tanks are more useful for the larger capacities, but consideration should be given to the actual head-range requirements under operating conditions in order to secure the most economical and practical installation.

Standpipes with a narrow leg are prevented from freezing by the natural insulation provided by the ice which forms on the inner wall, and by the convection currents set up as the cold water falls and the warm water rises in the pipe. The leg

is usually insulated by wood sheaves, packed inside with ground cork or sawdust.

Wooden Tanks.—Wooden tanks for water are generally made of cypress. The thickness of the staves varies with the capacity, 2 in. being used for capacities up to 10,000 gal., 2½ in. up to 20,000 gal. and 3 in. for larger sizes.

TABLE 14.—STANDARD, HEMISPHERICAL-BOTTOM, ELEVATED TANKS[1]

Capacity, U. S. gallons	Tank dimensions				
	Diameter	Cylindrical height	Overall tank height	Height of towers to bottom of tank capacity	
				Three-panel towers	Four-panel towers
25,000	15 ft.	14 ft.–7 in.	19 ft.–11 in.	75 ft.–0 in.	100 ft.
30,000	15 ft.	18 ft.–5 in.	23 ft.– 9 in.	75 ft.–0 in.	100 ft.
40,000	17 ft.	18 ft.–5 in.	25 ft.– 1 in.	75 ft.–0 in.	100 ft.
50,000	19 ft.	17 ft.–7 in.	25 ft.– 7 in.	75 ft., 83 ft.–4 in., 100 ft.	100 ft.–8 in.
60,000	19 ft.	22 ft.–6 in.	30 ft.– 6 in.	75 ft., 100 ft.	100 ft.–8 in.
75,000	21 ft.	22 ft.–6 in.	30 ft.– 6 in.	75 ft., 100 ft.	100 ft.–8 in.
100,000	24 ft.	22 ft.–6 in.	31 ft.– 0 in.	75 ft., 100 ft.	100 ft.–1 in.

[1] All above tanks have four columns. *Pittsburgh-DesMoines*

Water-service Demands.—The demands for personal water service and processing service have been the subject of considerable study and data have been obtained from actual service demands, indicating the requirements of many types of establishments. The data given in Table 15 present average water-supply requirements for the various types of building included. These factors, of course, will vary somewhat, depending upon the class of service to which a building is put, the number and character of water users, and factors of waste, water leakage, etc. However, in general, these figures will give an adequate basis for intelligent calculation of the total water demands for any class of building. The rates per fixture given in the table are based upon an equal number of men and women tenants. If men are in the majority, the factors may be decreased by 33 per cent. Where the total number of fixtures exceeds 150, the total pump capacity figured from the rate of consumption per fixture may be

reduced 25 per cent. It is always desirable to provide for a pressure at the fixtures of 30 to 40 lb. per square inch.

TABLE 15.—WATER-SUPPLY REQUIREMENTS

Building type	Minimum consumption per capita per day, gal.	Water consumption per fixture, gal. per min.
Apartments and apartment hotels...	45	0.75
Asylums........................	150–200	1.00
Dormitories and boarding schools...	100	0.90
Homes for the aged..............	100	0.90
Hospitals......................	150–200	1.00
Hotels.........................	150–200	0.80
Office buildings................	45	0.75
Sanitariums....................	150–200	1.00
Schools and colleges............	50	0.80
Stores and shops................	45	0.75
Swimming pools..................	500	....

Flow of Water in Pipes.—In the handling of liquids, the loss of head on account of friction in pipes is a considerable factor. Figure 31 shows a diagram for calculating pipe sizes, discharge velocities and loss of head in gas and water pipes. Too much piping is installed without previous planning, and a tremendous waste results. In designing a piping job, it is necessary to determine first the ultimate quantity of liquid to be handled. The loss of head through friction in each section of pipe can be obtained from Perry's "Chemical Engineers' Handbook," pp. 804–805. Short bends increase the pressure drop to a considerable extent, on which account as few bends as possible should be used. Instead, long-sweep or 45-deg. ells should be substituted where conditions permit. Heavy, viscous liquids must be pumped at much lower velocities if excessive friction loss is not to result.

The inside surface of the pipe has some effect upon resistance to flow of liquids. The results obtained from tables are accurate for ordinary wrought-iron water pipes, but the surface of cast-iron pipe is not so smooth or uniform. Care in installation of piping is essential. The pipe must be reamed to full diameter

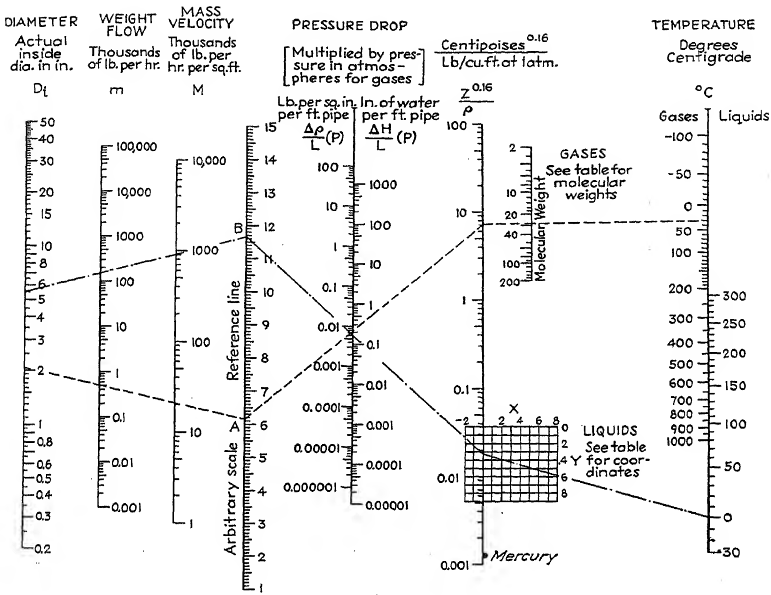

FIG. 31.—Fluid flow chart based on clean steel pipes. (*Courtesy of E. I. du Pont de Nemours & Company, Inc., Engineering Department, Technical Division, Wilmington, Del.*)

Directions for Using Chart.—This chart from the Chemical Engineering Catalog[1] is based on the Fanning equation: $\Delta P = 4fL\rho V^2/2gD$, and the following friction factor *vs.* Reynolds number relationship:

$$f = 0.04(DV\rho/\mu)^{-0.16},$$

which represents a safe straight line for commercial steel pipe in the turbulent region. The units in these equations are consistent; for example, in the f.p.s. system: ΔP = pressure drop, lb. per square foot; L = length, ft.; ρ = density, lb. per cubic foot; V = velocity, ft. per second; D = diameter, ft.; μ = viscosity, lb./(ft.) (sec.). In these units, the critical Reynolds number is about 2,100.

[1] From the Technical Data Section of the Chemical Engineering Catalog, pp. 104–105 (1940).

In the units used on the chart, the equation with the friction factor line substituted is $\Delta p = 0.1325L\mu^{0.16}m^{1.84}/\rho D_i^{4.84}$ and the critical Reynolds number in these units is about $m/\mu D_i = 0.33$.

For viscous flow, *i.e.*, Reynolds numbers below the critical, the Hagen-Poiseuille equation should be used. In the units used on the chart, the equation is $\Delta p = 0.034L\mu m/\rho D_i^4$.

Gas Example.—Air at a pressure of 120 lb. gage and a temperature of 30°C. is flowing at the rate of 500 lb. per hour through a 2-in. standard steel pipe. What is the pressure drop per foot of pipe? The actual inside diameter is 2.067 in. The pressure of the air is $(120 + 14.7)/14.7 = 9.16$ atm. abs. Connect $D_i = 2.067$ with $m = 0.5$ and extend the line to intersect the reference line at $A = 6.15$. Connect 30°C. on the gas-temperature scale with molecular weight = 29 and intersect the $\mu^{0.16}/\rho$ line at 7.1. Join this last intersection with point A, intersecting the $\Delta p(P)/L$ line at 0.008. The pressure drop is then $0.008/9.16 = 0.00087$ lb. per square inch per foot of pipe.

Liquid Example.—A 35 per cent calcium chloride brine is to be pumped through a line at 250 gal. per minute at a temperature of 0°C. If the allowable pressure drop is 0.006 lb. per square inch per foot of pipe, what size of pipe is required? Connect 0°C. on the liquid-temperature scale with the intersection of grid values $X = 2.6$ and $Y = 4.2$ shown in the table of "Coordinates for Liquids." Extend the line to $\mu^{0.16}/\rho = 0.0179$ and connect that point to $\Delta p/L = 0.006$ and extend to the reference line at point $B = 11.65$. Connect point B through $m = 147$ (since at density of 73.3 lb. per cubic feet, 250 gal. per minute = 147,000 lb. per hour) to intersect at $D_i = 5.5$ in., indicating a 6-in. pipe.

Molecular Weights of Gases

Acetylene	26.0	"Freon 114"	170.9
Air	29.0	Helium	4.0
Ammonia	17.0	Hexane	86.1
Argon	39.9	Hydrogen	2.0
Bromine vapor	159.8	Hydrogen bromide	80.9
Butane	58.1	Hydrogen chloride	36.5
Butylene	56.1	Hydrogen cyanide	27.0
Carbon dioxide	44.0	Hydrogen fluoride	20.0
Carbon monoxide	28.0	Hydrogen sulfide	34.1
Chlorine	70.9	Methane	16.0
Cyanogen	52.0	Methyl chloride	49.6
Ethane	30.1	Nitric oxide	30.0
Ethylene	28.0	Nitrogen	28.0
Fluorine	38.0	Oxygen	32.0
"Freon 11"	137.4	Pentane	72.1
"Freon 12"	120.9	Propane	44.1
"Freon 21"	102.9	Propylene	42.1
"Freon 22"	86.5	Sulfur dioxide	64.0
"Freon 113"	187.4	Water	18.1

Coordinates for Liquids (and Aqueous Solutions)

	X	Y		X	Y
Acetaldehyde	−0.3	3.7	"Freon 113"	0.9	6.2
Acetic acid, 100%	1.0	4.0	"Freon 114"	−0.4	6.2
Acetic acid, 77%	2.6	3.8	Glycerol, 100%	6.9	1.8
Acetic anhydride	0.7	4.3	Glycerol, 50%	3.0	3.7
Acetone, 100%	0.9	3.4	Hydrochloric acid, 31.5%	1.1	4.2
Acetone, 35%	2.7	3.7	Linseed oil, raw	3.4	1.8
Ammonia, anhydrous	0.9	3.6	Mercury	See Chart	
Ammonia, 26%	1.9	3.6	Methanol, 100%	0.8	3.3
Aniline	2.5	3.4	Methanol, 40%	2.8	3.6
Benzene	0.6	3.6	Methyl acetate	0.0	4.2
Butanol	2.6	2.6	Methyl chloride	−0.8	4.3
Calcium chloride brine, 25%	2.6	4.2	Nitric acid, 95%	0.8	5.8
			Nitric acid, 60%	1.5	4.8
Carbon disulfide	0.0	5.6	Nitrobenzene	1.7	4.4
Carbon tetrachloride	0.7	6.0	Octane	0.4	2.7
Chloroform	0.0	6.0	Phenol	2.4	3.4
Chlorosulfonic acid	1.5	5.8	Propionic acid	0.6	3.8
Cyclohexanol	5.3	2.2	Sodium chloride brine, 25%	2.1	4.4
Diphenyl	0.0	3.5			
Ether	−0.3	3.2	Sodium hydroxide, 50%	5.3	3.7
Ethyl acetate	0.2	3.9	Sulfur dioxide	−0.2	6.1
Ethyl alcohol, 95%	1.9	3.0	Sulfuric acid, 110%	3.7	4.7
Ethyl alcohol, 45%	3.6	3.4	Sulfuric acid, 98%	3.5	4.8
Ethyl chloride	0.2	4.3	Sulfuric acid, 78%	3.2	4.8
Ethylene glycol.	3.5	2.9	Tetrachlorethylene	0.3	6.2
Formic acid	1.5	4.5	Toluene	0.4	3.6
"Freon 11"	0.0	6.2	Trichlorethylene	0.1	5.9
"Freon 12"	−1.2	5.9	Turpentine	1.1	3.1
"Freon 21"	−0.4	5.9	Vinyl acetate	0.4	4.2
"Freon 22"	−1.7	5.5	Water	2.0	4.2

after cutting, and care should be taken to remove sand, rust or scale by standing the pipe on end before it is put in place.

Each fitting material affects the flow of water, producing a loss in head that can be calculated in terms of pipe length as shown in Fig. 32. Choose pipe fittings that will allow free flow; use gate valves instead of globe valves wherever possible. (See Perry's "Chemical Engineers' Handbook," p. 825.)

Economical Pipe Selection.—In choosing the size of pipe to be used, the selection should be based on both cost of pipe and cost of power. A small pipe costs less, but the friction is greater and

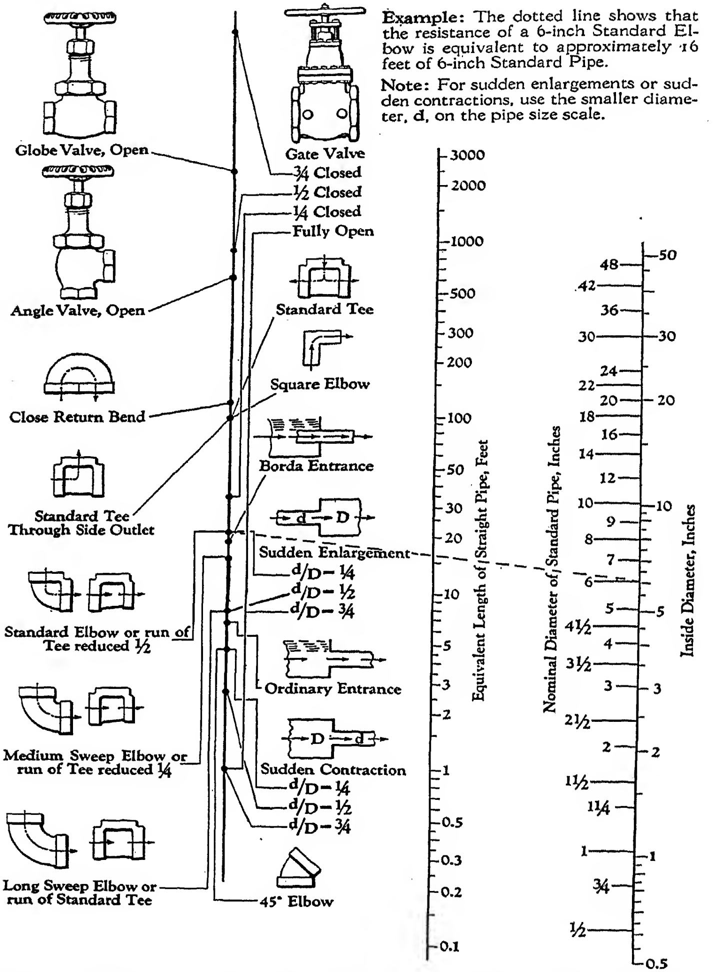

FIG. 32.—Resistance of valves and fittings to flow of fluids. (*By permission of Crane Company.*)

this increases the power bill. A larger pipe in many instances will save more in power bills than the additional investment in pipe will cost. Furthermore, the larger pipe may so reduce the total pumping head that a lighter and lower priced pump and drive may be used. It is not unusual to see a pipe line several sizes larger than the pump-discharge connection.

From Table 16 it is possible to determine how much power a pipe line of a certain size takes, handling a certain quantity of water. By comparing the pumping cost with the total cost of the pipe line, which should include interest on the investment, depreciation, maintenance and cost of erection, the engineer will be able to decide what size is the most economical for his plant. (Also see Table 101 and Fig. 66, Chap. XII.)

TABLE 16.—POWER CONSUMPTION OF PIPES[1]
(Theoretical horsepower for pumping water through 1,000 ft. of new iron pipe[2])

Flow, gal. per min.	Pipe size, in.							
	1¼	1½	2	2½	3	4	5	6
50	5.4	2.5	0.9	....	....	....	....	...
75	...	8.0	2.8	0.9	....	....	....	...
100	...	18.3	6.4	2.1	0.9	....	....	...
150	...	....	20.3	7.1	2.9	0.6	....	...
200	...	....	....	15.5	6.5	1.5	....	...
300	...	....	....	....	20.5	5.0	1.7	...
400	...	....	....	....	....	11.3	3.8	1.6
500	...	....	....	....	....	21.6	7.3	2.9
600	...	....	....	....	....	....	12.2	5.1

[1] Goulds Pumps, Inc.
[2] Does not include pump efficiency.

CHAPTER VI

THE BUILDING

INDUSTRIAL BUILDINGS

Engineers engaged in designing chemical plants must take into consideration location, climatic conditions and the nature of the chemical industry which the plant is to house in deciding on type or types of building construction to adopt. The process and the materials handled will indicate the general design requirements. Careful attention must be given to the type of floor, structural frame, walls, roof, fume handling, drainage, ventilation, heating, and foundations of both building and equipment. Although experienced engineers can determine the proper building practices, information regarding relative costs of different forms of structure is valuable for preliminary survey purposes for the chemical engineer. Usual industrial buildings are of two types: (1) *multistory;* and (2) *single-story.* In certain of the chemical engineering industries the multistoried building (or, at least, a tall single-story building) is required where gravity flow from point to point in the process is absolutely necessary. In such a case equipment must be supported at different levels, either on different floors of a multistoried building, or on working platforms independent of the building wall and reached by open stairways.

Buildings to house chemical and process plants are probably more frequently governed by the type of equipment to be used in manufacturing than any other type of industrial building. In fact, in many instances the building becomes merely an enclosure to protect the process and the equipment involved from the weather. Still, there are cases where the structure is designed to support a considerable amount of equipment at various levels within the building itself; whereas, on the other hand, particularly where process and climate will permit, there is an increasing tendency to use process equipment and machinery of an outdoor or unhoused type.

Where plant additions must be made in congested areas, space for single-story construction may not be available except at prohibitive cost. The general tendency of industry in recent years, to move from congested central districts to outlying communities, has been attended by a great increase in the number of single-story buildings, built where land is cheap and taxes low. However, modern industry is coming to find out that the single-story type is preferable, almost without regard to taxes are and land values.[1] For many industries, the single-story building is the most efficient and economical, whether land cost is $50 or $2,000 an acre.

That *multistory buildings*[2] are less expensive per square foot than single-story buildings is a common misconception, based on the fact that the structural floor of a multistory building serves also as a ceiling for the story directly beneath it. In contrast to this, the single-story building naturally must have a floor and roof for every square foot of floor space. However, there are factors that more than offset this. For example, multistory buildings practically all have basements that must be excavated. Basement walls are heavier than other walls in all buildings, and considerable expense for waterproofing of the basement walls and floor is entailed. The cost of stairs, elevators, approaches, outside and interior walls and wall columns bulk high in the multistory building. Cost of elevators and their commonly required enclosing walls is a large item, and most multistory buildings of fair size require either two freight elevators and one passenger elevator, or one of each type. Building codes usually call for at least one stairway at each end of a multistory building, and these must be enclosed in fire walls at added expense. The frequent heavy live-load requirements put on multistory building floors often increase the cost of multistory construction.

Single-story buildings, with some few exceptions, are less expensive than the multistory type in original cost, maintenance cost and operating cost. The increasing intensity of industrial competition, making economical and efficient straight-line production virtually a matter of self-preservation for the manufacturer, requires the use of the single-story plant in the great majority of cases. In the single-story building, the load the

[1] KAHN, M., *Factory Management and Management*, **95**, 51 (1937).
[2] STITT, H. E., *Chem. Met. Eng.*, **38**, 196 (1931).

floor will carry usually is limited only by the bearing value of the soil on which the floor rests. Most soils have a bearing value of many thousands of pounds per square foot.

Flexibility is another important advantage of the single-story building. If a manufacturer finds it necessary to effect radical changes in product or method, he may find a multistory building unsuited to the new production scheme, whereas a single-story building lends itself to almost any kind of arrangement, because of the absence of large columns and the uniformly high floor-loading capacity.

Industrial buildings ordinarily divide themselves into a few simple types about as follows:[1]

1. Flat-roof buildings may be either single- or multistory and are often used where it is advisable to house a number of tanks or other vessels or equipment on or above the roof. Although there are a good many flat-roof buildings in use in the chemical industry, as well as in many other manufacturing uses, it is usually advisable to eliminate traffic of any sort over roof surfaces in order to avoid possible mechanical damage or punctures that will result in leaks. Many plant operators feel, too, that it is advisable to get water and snow off the roofs as soon as possible and therefore frequently insist upon pitched roofs with fairly steep angles.

2. Pitched-roof buildings may be of single- or multistory design. In either case this type of roof is often combined with a monitor that may be designed to give additional interior daylighting in the building or to be equipped with louvers for ventilation. In many cases ventilated types of sash provide both ventilation and interior illumination.

3. Sawtooth buildings are usually best located with the glass in the sawteeth facing directly north. Although somewhat expensive, there are distinct advantages in lighting and visibility in a building having the *sawtooth* type of construction. For certain kinds of plants, notably those in which macroscopic examination of processed materials is important, as in dyeing, it is the only proper type. Direct sunlight is excluded, and the time of use of artificial lighting during the day is considerably reduced. There is a uniform diffusion of light to all parts of the space, which makes all space working space. The disadvantages lie in the roof

[1] FERGUSON, H. K., *Chem. Met. Eng.*, **48**, 5—97 (1941).

construction, and special care must be exercised in design. Leaks, excessive loss of heat, excessive condensation on the underside of the roof and poorly controlled ventilation are commonly encountered in sawtooth construction. The cost of construction is greater due to the cost of windows, glazing, special flashing, condensation conductors for skylights and higher cost of heating.

Windowless and blackout plants are considered in certain types of defense industries but give promise for selective adoption in process and chemical plants. Where it is important to the process to maintain temperatures and/or humidities within narrow ranges, or where air conditioning is essential for other reasons, this type of design may find more general application.

UNHOUSED PLANTS[1]

Industrial operations are commonly conducted inside of buildings in order to afford shelter to the workmen, the manufacturing equipment, the raw materials, intermediates and products. Many large chemical manufacturing operations, however, have little need for buildings because the number of workmen per unit of factory space is generally small, the equipment is of such a nature that it either needs no shelter, or it can be protected more economically without a building and finally, the materials needing protection do not emerge from the equipment except at one or perhaps a few points where specifically designed structures afford the most economical shelter.

The awakening to large economic advantages resulting from the unhoused and semihoused types of construction is partly due to the fact that the larger the factory the more profitable it may be. Also the above types are well adapted to the South, where the weather is inclement only a short time and the lack of shelter during such periods is only a transitory inconvenience. Then one must consider that there are three elements to shelter, *viz.*, attendants, equipment and materials; very seldom need all three be accorded the same treatment regarding shelter; quite frequently only one needs shelter continuously, the other two but occasionally.

Sheltering Attendants.—The general principle involved in affording shelter to workmen is to arrange his duties and facilities so that little space be needed. If instruments show the

[1] DEUTSCH, Z. G., *Chem. Met. Eng.*, **48**, 5—100–101 (1941).

temperatures, pressures, concentrations, flow rates and other factors of control by the operator, then the installation of an instrument panel, with push button, lever or control wheel alongside each instrument will permit the operator to observe at all times his duties to the processing equipment in a small well-placed shelter right among the equipment. In addition to instruments, it is well to adopt scattered shelters in unhoused plants by the simple expedient of centralizing pumping, lubrication, control sample lines for routine filtration and automatic sampling being carried to a central control room. The percentage of time during which rain is falling is very small; it seems poor economy to provide shelter for maintenance workmen on occasional jobs, which, 99 times out of a 100, actually furnishes no shelter to anyone.

Shelter of Equipment.—Equipment must be sheltered from adverse weather effects, destructive effects of adjacent processing and deleterious local atmospheric conditions. Protection of equipment from the weather is relatively simpler than protection from corrosive fumes or abrasive dusts. Special equipment is often housed in shelters provided with effective air conditioning as protection from fumes or dust. Not too extensive corrosive atmospheres can be combated inexpensively by using the proper protective paints. However, changes in heat effects are not so readily corrected. In some cases the heat lost is of negligible value but yet can so upset the control that it becomes necessary to provide adequate insulation; there can be considerable difference in heat loss between day and night, sunshine and shade, still air and moderate winds. A layer of heat insulation covering the exterior of the equipment gives more effective control of these losses than can be found in uninsulated equipment in the usual type of factory building.

Heat insulation requires careful protection from the weather, not only to prevent loss of insulating properties, but also to prevent damage to the insulation through leaching and/or segregation. A fairly strong outer coating, finished off with a waterproof or repellent layer or film, provides protection from rain. Heat insulation needs maintenance service, and provisions should be made for replacement of sections or repair to areas.

Shelter of Materials.—The protection of raw materials, intermediate by-products and products from the weather and

local atmosphere may not be so troublesome as the protection of workmen and equipment. All soluble solids and products of high purity must be completely protected, as must products packed and loaded for shipment. Coal, rocks and ores need no shelter, and many bulk materials can be cheaply protected in storage in cylindrical, spheroidal or spherical tanks. Segregation of materials differing considerably in nature can be accomplished more effectively by mixed housed and unhoused types of shelters.

Welded Trusses.—Of recent origin, developing with welding technique, is the *rigid-frame* construction of trusses, reducing the many steel members which ordinarily obstruct light. These trusses permit the utilization of the entire building interior, reduce plant maintenance costs, lower depreciation and permit greater flexibility in accommodating plant operations. The portable truss is also available for greater flexibility in internal utilization of space.

Materials of Construction.—For types of building construction for the chemical plant, and description of the various building methods and materials ordinarily available, together with appropriate cost data, it is suggested that the building code recommended by the National Board of Fire Underwriters, of New York, be consulted.[1] The following classification of buildings is represented in this code.[2]

1. *Frame Construction.*—The exterior walls or portions thereof of wood; also a building with wooden framework veneered with brick, stone, terra cotta, or concrete; or covered with plaster, stucco, or sheet metal.

2. *Nonfireproof Construction.*—*a.* Ordinary Construction. A building having masonry walls, with floors and partitions of wooden joist and stud construction. The supporting posts and girders may be of wood or of protected metal.

b. Mill Construction (sometimes called "slow-burning construction"). A building having masonry walls and heavy timber interior construction.

3. *Fireproof Construction.*—Consists of masonry, steel, or reinforced-concrete construction.

Flooring.—An industrial flooring should be chosen with a view to combining as many of the following properties as possible, consistent with the conditions to which the floor will be subjected:

[1] Vernam, H. D., *Chem. Met. Eng.*, **48,** 5—112 (1941).

[2] Parker, H. R., *Chem. Met. Eng.*, **33,** 545 (1926).

Attractive.	Flexibility.
Low initial cost.	Nonabradability.
Low installation cost.	Nonslip quality.
Low maintenance cost.	Quietness.
High strength.	Sanitary quality or cleanability.
Noncorrodibility.	Waterproof quality.
Resiliency.	Fire resistance.
Durability.	Thermal insulation.
Shock resistance.	Ease for fastening equipment.

According to Fitzmaurice and Lea,[1] factors to be taken into account in flooring for chemical plants are:

1. Resistance to wear and abrasion including maintenance and ease of renewal.
2. Durability in terms of chemical resistance to materials likely to come in contact with the floor, combined with (1) above.
3. Comfort in terms of (*a*) hardness, (*b*) warmth, (*c*) noisiness, (*d*) slipperiness.
4. Changes in volume. Drying shrinkage is the most important.
5. Appearance, new and worn, and ease of cleaning.

The type of flooring to be used in a chemical plant can be ascertained from the data given in Table 17. The combinations obtainable in floor material are many, and it may be necessary to combine some of the types in order to secure the desired properties.

Machine shops, textile mills and similar plants which require the employee to stand for a considerable part of the day, are usually built with a *heavy wooden* floor or a *wood-block* floor on a concrete subbase. Foundries, steel fabricating shops and boilers shops generally use *dirt* floors. Chemical plants demand a floor that will stand up under extreme conditions of acid and alkali exposure. *Concrete* or *brick* is used largely where heavy storage and constant trucking give an unusually severe test to the floors. *Steel* is especially adaptable to mezzanine floors and platforms because of the ease with which a strong and permanent floor can be installed. The use of *steel grating* will give more light to the space below and also give a floor that will be less dangerous to the workmen because of the elimination of slippage. A heavy steel plate is sometimes laid over the wood

[1] Fitzmaurice, R., and F. M. Lea, *Trans. Inst. Chem. Engrs.* (London), **17**, 30 (1939).

in the aisles of storerooms to give a truckway that will not wear out so rapidly as wood.

Special conditions of use sometimes dictate an unusual type of floor covering, as, for instance, a lead pan to save drips, under specific equipment or over an entire building floor. *Rubber* has been applied to bridges, roads and, in limited cases, to floors. *Asphalt* has been used as a protection for concrete but is open to the objection that it will not stand up under heavy loads, especially when exposed to even moderate heat. The more recent floor coverings of such materials as *mastic* (asphalt and Portland cement) which have been worked up with an inert filler, render excellent service for general conditions. They are cheap and can readily be applied over an old floor. Some *acidproof cements* have recently been placed upon the market which can be poured in place and which harden to a very serviceable floor. Their brittleness and poor resistance to abrasion under extreme conditions may, however, cause them to be eliminated in some cases.

Walls and Framework.—Steel or wood framework of buildings can be filled in with a number of combinations. *Concrete* is probably the best material to use for walls in a building of permanent construction, although *concrete and brick* are nearly ideal where the size of the project warrants the investment. Relative fire resistances of walls and partitions for brick, concrete, hollow tile, gypsum block and plaster have been compiled by Miner, Miller and Tilden.[1]

Sheet-metal construction of any kind has the advantages of cheap and quick erection. It will not be found desirable in the colder climates as this type of building is hard to heat, unless insulating lumber is used on one side of the sheet metal. However, for foundries and warehouses, sheet metal is very largely used since heating is unimportant and low initial cost is a major factor. Where corrosive conditions will not permit the use of unprotected metal, it is possible to use an asphalt and asbestos covering which will resist corrosion.

For both permanency and maintenance, the building framework should be of steel, built of heavy H-section columns and heavy floor beams to allow reasonable floor span. Floors should not be brought closer to steel columns than 6 in. and should have

[1] Perry, J. H., "Chemical Engineers' Handbook," p. 2882, McGraw-Hill Book Company, Inc., New York, 1941, 2d ed.

TABLE 17.—EFFECT OF VARIOUS AGENCIES ON FLOORING MATERIALS[1]

Flooring materials	Heat and light	Water	Alkalies	Weak acids	Common salt	Sulphate salts	Mineral oils and grease	Animal and vegetable oils and fats	Sugar (hot solution)	Milk
Wood.........	Shrinkage	Swelling colored extracts leached from oak	Strong alkalies destroy all woods. Some wood particularly oak, discolored by any alkali. Weak alkalies cause pickup of grain in resinous woods	Cause pickup of grain and gradual hydrolysis when dilute. Strong acetic acid has marked corrosive effect	Swelling and pickup of grain, particularly in resinous woods	Neutral salts have no action. Acid salts as for dilute acids	Oil absorbed no chemical action by hydrocarbons but acid impurities have same effects as for mineral acids	Oils and fats absorbed. No appreciable chemical action except for solvent effect on minor components	No appreciable chemical deterioration	No appreciable chemical deterioration
Rubber.......	Hardens and gets more brittle	None	Resistant	Resistant	None	None	Softened	Softened	Probably soften	
Linoleum sheet	Hardens and cracks	None	Attacked	None	—	—	—	—	—	—
Linoleum cork tiles	Harden and crack	Little	Attacked	None	—	—	—	—	—	—
Portland cement concrete and mortar finishes	Shrinkage	Slight swelling	None	Attacked	None except for very strong solutions	Attacked	None	Attacked	Attacked	Attacked
Aluminous cement concrete and mortar finishes	Shrinkage	Slight swelling	Attacked	More resistant than Portland cement to dilute solutions	None	None	None	Little action if free acids not present in appreciable amounts	More resistant than Portland cement	More resistant than Portland cement
Clay tiles......	None	None	Possible risk of deterioration owing to crystallization of salts if tiles very porous	None	As "alkalies"	As "alkalies"	None	None	None	None
Marbles and hard limestones	None	None	Little or none	Attacked	Possible crystallization effects	As "common salt"	None	None	None	As "weak acid"

TABLE 17.—EFFECTS OF VARIOUS AGENCIES ON FLOORING MATERIALS.[1]—(*Continued*)

Flooring materials	Heat and light	Water	Alkalies	Weak acids	Common salt	Sulphate salts	Mineral oils and grease	Animal and vegetable oils and fats	Sugar (hot solution)	Milk
Sandstones....	Shrinkage may occur	None	Possible risk of deterioration owing to crystallization of salts	Calcareous sandstones affected, others not affected	Possible crystallization effects	As "common salt"	None	None	None	As "weak acid"
Asphalt.......	Softening if temperature too high for grade used	None	Little or none	Affects normal asphalts, acid resisting or "chemical" asphalt with inert filler, *e.g.*, slate dust, required	None	None	Softens coal-tar pitch products more resistant	As "mineral oils"	Softening	Softens "chemical" asphalt with inert filler and granite aggregate preferable
Magnesium oxychloride	Liable to crack and buckle owing to dehydration	Must be protected by wax or oil. Not suitable under continuously wet conditions	As "water"	Attacked unless adequate protection by wax	As "water"	As "water"	Not harmful	Not harmful	—	—
Jointing materials										
Portland cement Aluminous cement	As under flooring materials, but attack proceeds more slowly. Joints should be as thin as possible									
Bituminous mastics	Slight softening. Joints apt to protude as ridges	None	Little or none	None if filler is inert, *e.g.*, asbestos or slate dust	None	None	Softens coal-tar pitch produces more resistant	As "mineral oils"	Slight softening	Slight softening
Glues[2]........	Used for sticking linoleum to base. Under damp conditions subject to softening and growth of molds									
Rubber solutions and Latex[2]	Used for sticking rubber or linoleum to base. Moisture causes deterioration of bond									
Drying oils[2]...	Used as a thin paste (like a paint) for sticking linoleum to base. Moisture may have destructive effect									

[1] FITZMAURICE, R., *Trans. Inst. Chem. Engrs. (London)*, **17**, 34 (1939).
[2] Not usually subjected directly to agencies enumerated above.
NOTE.—Dashes are inserted where material is not normally used under type of exposure indicated.

a substantial curb around the column, especially if subject to spills of corrosive liquors. Pockets in steel framing should be eliminated, as far as possible.

Hollow tile offers a compromise in cost between metal and heavy masonry. The tile walls are easily, quickly and cheaply erected and are not unduly expensive to maintain. However, it should be understood that they are primarily of temporary construction and subject to rather rapid deterioration on account of vibration or shock. This type of construction was very popular for war industry plants erected in the northern states. It has a further value in explosives plants in that it will disintegrate easily upon shock. The combination of hollow-tile walls with concrete pilasters is commonly used and results in a high-grade building of low initial cost.

Wooden walls are cheap, noncondensing, quickly erected and easily altered. A study of the fire hazard, corrosive action of fumes and insurance rates will generally be enough to show whether a wooden building is desirable for the industry under consideration. In the southern states wood is subject to splitting due to high humidity and temperature changes and is subject to rapid disintegration due to termite attack.

There has probably been no more noticeable change in building design during the past 10 years than the present tendency to install as much glass as possible in the walls and roof of buildings. The typical factory building of 20 to 30 years ago was constructed of heavy brick walls with large wooden-sash windows placed between brick piers as wide or wider than the windows, resulting in a glass area of considerably less than 50 per cent of the total wall surface. The average newly designed building of today has between 55 and 85 per cent of the space between the work table and the ceiling of glass. The cantilever construction of the Starrett-Lehigh building permits about 95 per cent glass. Such construction is cheaper than the old-fashioned heavy construction, permits the use of wider buildings and the consequent placing of equipment to better advantage, improves ventilation and working conditions, and results in more contented personnel. A disadvantage, of course, is the additional cost of heating such a building.

Roof.—The first requirement for the roof in the average chemical plant is that it should have a high degree of resistance

to corroding fumes; and the second, that it should be noncondensing, or as nearly so as possible. The problem is again the choice of a suitable material to meet the manufacturing conditions. A roof for a building in which an explosive process is carried out should be light and capable of disintegration upon shock.

The problem may be to resist heat, to give maximum light, to exclude the weather, prevent condensation, furnish ventilation and fire protection, and to combine any or all of the above with as strong and well appearing a roof as possible. Appearances, however, rarely enter into a factory design. The *steel roofs* of the train sheds in our larger cities are a good example of roofs that combine strength and lightness with unusually good appearance.

Wood shingles or the various *tar and gravel-specification roofs* are easy to erect, cheap and of reasonably long life. In some cases, excessive fumes may cause a rapid disintegration of the woodwork. In such cases a more resistant roof should be installed. Otherwise, however, a wood-and-tar roof is probably better for factory purposes than concrete or steel, as its thermal conductivity is lower, thus improving working conditions, reducing condensation and lowering the heating costs.

Slate is noncorrodible, quickly laid and unusually durable. It is, however, somewhat expensive for factories and is also subject to heavy condensation. The same objections can be applied to a *tile roof.* Scaffolding is necessary for installation, and repairs are hard to make.

Tin, copper, lead, aluminum and zinc roofs are long-lived. They are, however, expensive and subject to corrosion in specific cases and are, therefore, not generally applicable to chemical plants.

Concrete, either in the monolithic form or as precast slabs, makes an unusually good roof. It is not so subject to corrosion as most other types and is fireproof. The objections of higher installation cost, excessive condensation and greater weight per unit of thickness may be enough to swing the decision in favor of some of the other types.

Corrugated iron is especially suited for buildings of a temporary character but has nothing to recommend it for permanency. An improvement results when the corrugated iron is covered with

a heavy tar paint and in some cases asphalt and asbestos. Such a roof is cheap, lasting, easily erected, quite resistant and largely self-supporting. Only a light steel framework is required.

An unusually durable and fireproof roof is obtained by the use of *asbestos and concrete corrugated board,* which can be installed with the ease of sheet iron. Such a roof does not need paint, will not rot and is practically permanent. This material can also be obtained in the form of flat shingles which can be placed over an old shingle roof. Thus an actual advantage is obtained by securing a roof which is thicker than usual, better insulated, and therefore noncondensing.

Gypsum roofs are much lighter in weight per unit thickness than any other material, are fireproof, easy to install and the least condensing roof obtainable. Such a roof can be obtained in precast slabs or laid as a monolithic roof. Chemically, gypsum is more inert than most roofing materials and is, therefore, suitable for chemical plant construction. Such a roof is also an excellent light reflector and makes a better appearing interior than most other roofs.

The perfect adhesion of *built-up roofing felts and insulation* to the steel-deck type of roof, on which such coverings are often installed, enables the roofer to make a positive guarantee of roof service. Roofing felts do not fracture when laid on insulated steel roof decks, as is the case with roof decks that expand and contract during temperature changes. When built-up roofing is applied to concrete roof slabs and gypsum roof slabs, a priming coat before the laying of built-up roofing is required to ensure a good bond, whereas wood roof decks require the nailing of built-up roofing to ensure bond.

Loads on Roofs.—There are two types of load on roofs which must be taken into consideration in a chemical building: (1) dead load, consisting of structural load, such as roof surface, trusses and purlins; and (2) live load, consisting of snow and wind load. The design of roofs, columns and foundations is the task of the architect, and to him the chemical engineer must go to obtain the correct design for the building. However, oftentimes the chemical engineer is interested in rough estimates on roof loads when some situation arises where an architect cannot be consulted and a shelter of some type must be provided. Especially is it essential to the chemical engineer to be able to

answer a question on additional loads on structures should replacement or new construction be considered in an old structure. Table 18 contains dead-load data for roofs, excluding steel-truss work.

TABLE 18.—WEIGHT PER SQUARE FOOT OF ROOF SURFACE[1]

Material	Pounds	Material	Pounds
Common shingles	2.5	5-ply felt and gravel	6.0
Slate shingles, ¼-in.	9.6	4-ply felt and gravel	5.5
Plain tile shingles	11.0	3-ply ready roofing	1.0
Copper sheet	1.5	Skylights, 5⁄16-in. glass	5.0
Tin sheet	1.0	Wooden sheathing, 1-in.	3.5
Corrugated iron, galvanized or painted, 26 gage	1.0	Rafters, 2- by 4-in., span 16–20 ft.	1.5
Corrugated iron, galvanized or painted, 24 gage	1.3	Rafters, 2- by 6-in., span 16–20 ft.	1.8
Corrugated iron, galvanized or painted, 22 gage	1.6	Rafters, 2- by 8-in., span 16–20 ft.	2.5
		Purlins, span 16–20 ft.	2.5

[1] KIDDER, F. E., and H. PARKER, "Architects' and Builders' Handbook," 18th ed., pp. 1394–1395, John Wiley & Sons, Inc., New York, 1931.

For live loads, consideration must be given to wind and snow, calculated on the vertical. Simplified data for estimating these live loads appear in Table 19. Additional data on weather conditions, including direction and intensity of winds, are compiled by Hillen, in Perry's "Chemical Engineers' Handbook," pp. 1109–1111.

TABLE 19.—COMBINED WIND AND SNOW LOADS IN UNITED STATES[1]
(In pounds per square foot of roof)

Section of United States	Slope of roof				
	60 deg.	45 deg.	30 deg.	20 deg.	Flat
Southern and Pacific coast	28	26	24	20	30
Central and Western states	28	26	24	30	35
Northwestern and New England states	28	26	24	35	40

[1] KIDDER, F. E., and H. PARKER, "Architects' and Builders' Handbook," 18th ed., p. 1399, John Wiley & Sons, Inc., New York, 1931.

Design of Standard Buildings.—Designing a building is not necessarily a function of the chemical engineer in plant design;

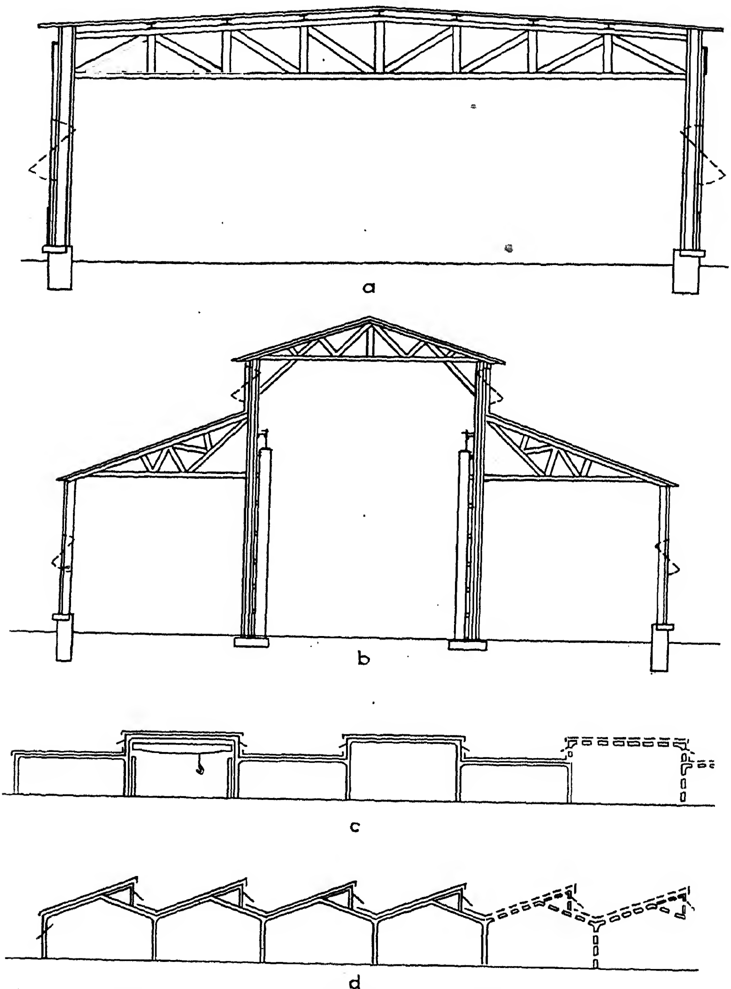

FIG. 33.—Types of standardized single-story buildings. *a.* Truscon type B. *b.* Truscon type 3-M. *c.* Austin monitor type, rigid-frame construction. *d.* Austin sawtooth, "whaleback" rigid-frame construction.

more often he finds available for his use buildings of standard design, so that all he needs to do is to indicate his needs to the manufacturers of such buildings. Figures 33 and 34 show several of the available types of standardized buildings.

The constructed units that make up standardized buildings are so designed that in many cases they are interchangeable, and in most cases are flexible in their applicability. As a result of this feature it is possible to use a number of standard prefabricated trusses, singly or in combination, together with framing members, roofing, and siding panels to give any desired cross section. The building may be extended in length, usually in multiples of 2 ft., to cover any area. Furthermore, various heights may be achieved in the same building so that, for example, one section can be of low single-story design and an adjacent part of high single- or multistory type to provide for equipment on several levels.[1]

Equipment and building departments of industrial building manufacturers are often in a position to supply equipment for the following services, or at least to provide plans and assist in installation:

1. Heating systems, both direct and indirect, with boiler plants and all necessary mechanical equipment.
2. Ventilating and air-conditioning systems.
3. Complete modern electric lighting systems, designed and installed by engineers who are familiar with the different lighting intensities best suited for every industry.
4. Installation of complete power wiring systems for all electrically driven machines.
5. Complete installations of sanitary plumbing and systems for sanitary drainage, storm-water drainage, waste disposal and water supply.
6. Sprinkler systems with storage tanks, towers, etc.
7. Complete steam-power plants for generating electricity or for producing process steam, or both.
8. High- and low-pressure steam, water, gas, air and all other kinds of process piping.
9. Elevators for passengers and freight.
10. Installation of machine foundations and machinery; overhead systems for shafting and crane supports, with cranes mechanically or manually operated.
11. Conveying equipment for handling all types of products in the plant.

[1] Prefabricated and Standard Plant Buildings, *Chem. Met. Eng.*, **48,** 5—102 (1941).

Selection of Building Type.—The selection of the type of building is influenced by many factors, including the use, size, cost, life, maintenance, insurance, alterations, environment, climate, hazards, floor loads, price of products, adjoining plants, cubical contents desired, flow chart of process and expansion. Several of these factors are controlled by the product for which the building is to be used, and it is therefore of little value to discuss the advantages of one type of construction over another until something is known of the process to be carried out in the building. The intelligent and careful selection of the construction materials used will result in an economical solution in each specific case. The choice of materials used in various types of chemical plants is immediately reflected in the maintenance cost of the building and ultimately in the general overhead charged against the product manufactured. Obviously, the layout of the process will be given first consideration in the design of the building and will dictate whether a multiple- or a single-story building will be used.

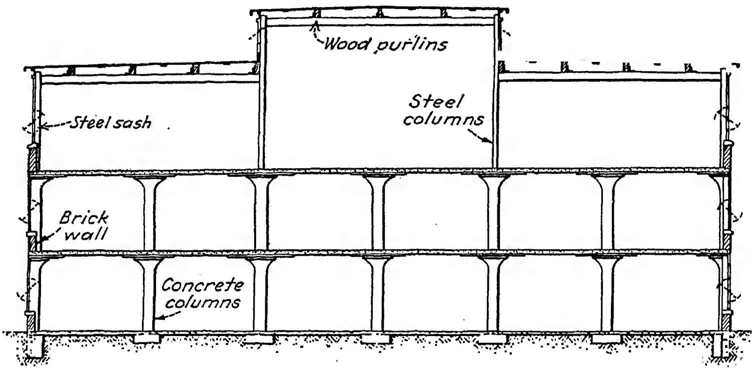

FIG. 34.—Austin multistory industrial building.

As a supporting structure for the building it will be necessary to have a secure foundation, by the use of concrete, rubble, masonry or brick. In some cases the ground conditions may even make piling necessary or a combination of piling and concrete slabs. These piles may be of wood, concrete or a combination with steel shell.

Selection of Building Equipment.—After the building has been selected, it is necessary to give consideration to the choice of layout and equipment for building services, including personnel facilities,[1] fire protection and other safety measures, illumination, ventilation and heating.

Safety Measures.—Safety requirements in industrial plants should be determined from the safety codes of the various engineering societies, and of insurance and protective associations. A brief review of safety measures is given by Miner, Miller and Tilden.[2]

Fire Protection.—Adequate fire-protection engineering concerns every business executive and every public official. The increasing losses year after year resulting from destructive fires make prevention and protection a pertinent subject. Fortunately, architects, engineers, insurance underwriters and managements realize the importance of the problem and are seeking constantly to employ the most modern protective devices to reduce risks and eliminate fire hazards.[3] It is literally true that every unprotected risk is paying for a fire pump or sprinkler installation. The underwriters' rates are based on perfect protection, and the lack of sprinklers, fire pumps or other protective equipment penalizes the risk and subjects it to a higher rate. Savings in insurance premiums, varying from 60 to 85 per cent, usually accrue from approved installations and on that basis will soon repay the original investment, assuring a net profit thereafter. *Centrifugal fire pumps* are used as a source of water supply for automatic sprinkler, standpipe, or hydrant fire-protection systems. They are also employed as booster pumps in areas of low city-water pressure, or in installations where a gravity water-supply tank cannot be used.

The *automatic sprinkler* consists of a water-distribution system, available to all parts of the plant, which automatically opens a jet at the point of fire when the application of heat to a fusible link or joint sets off or trips the stop in the sprinkler. These systems may be either the wet-pipe or dry-pipe type. In the wet-pipe system, water is constantly in the pipes up to the

[1] Maynard, F. W., *Chem. Met. Eng.*, **48**, 5—108 (1941).

[2] Perry, J. H., "Chemical Engineers' Handbook," Sec. 28.

[3] Oakhill, F., Plant Fire Protection Data Sheet, *Factory Management and Maintenance*, **95**, 109 (1937).

sprinkler heads. Where temperatures below freezing exist, the dry-pipe system is used, wherein air under pressure fills the pipes in the buildings and any release of the pressure automatically opens an underground or protected valve. There is some lag in the dry-pipe system on account of the necessity for the water to force out the air before it can be applied to the fire. This often results in the fire gaining costly headways. The supply of water may come from a primary storage tank and a secondary service main, or from a secondary source such as a pump which automatically cuts in when the water demands increase owing to fire. *Fire pails* are very efficient means of fighting fires because they check a fire at the start. They should be well distributed, well filled with either water or sand, and periodically inspected. *Fire extinguishers* are useful in extinguishing small fires and are of four varieties, including those containing sodium carbonate solution and an acid bottle; those using solutions of aluminum sulfate and sodium carbonate (Foamite); those filled with carbon tetrachloride; and the relatively new type containing liquefied carbon dioxide under pressure. With fires of oil and volatile inflammable liquids the last three may be used; with electrical fires, the last two. Table 20 classifies the five types of extinguishers most commonly used in chemical plants.

A compilation of a large number of chemicals according to flash and fire points and explosive limits as compiled by the National Fire Protection Association appears in Table 21.

Piping and Hose for Fire Protection.—Fire hydrants and fire-protection equipment should be placed at strategic points in a plant. The hose should be reeled or hung at a convenient height on some form of easily unreeled or unhooked hanger, permanently attached to a pipe line. The company in which the plant is insured determines the usual specifications for inside service such as the hose valves, the racks, and the requisite quantity and size of hose coupled with nozzles, either for the pump room, for service inside the building, or for outside service; in the last case the underwriters require a hose house, complete with hose.

For public buildings, standard practice calls for a 2½-in. valve for use of the local fire department, and either an auxiliary 1½-in. valve or a reducing coupling (as may be required by the municipal code), 1½-in. hose to be attached to the valve.

TABLE 20.—CHARACTERISTICS OF FIRE EXTINGUISHERS

Type		Foam	Soda and acid	Antifreezing	Tetrachloride	Carbon dioxide
Chemicals employed		Al_2SO_4 and $NaHCO_3$ (with foaming agent)	H_2SO_4 and $NaHCO_3$	$CaCl_2$ (special grade) safety fuse cartridge	CCl_4—heated	Compressed CO_2
Method of operating		Invert	Invert	Invert	Pump	Open valve
Method by which pressure is created		Chemical reaction	Chemical reaction	Burning of safety fuse	Pumping action	Own pressure
Effective range of stream		30–40 ft.	30–40 ft.	30–40 ft.	20 ft. or more under full pump press	Variable
Rated liquid capacity of most common size		2½ gal.	2½ gal.	2½ gal.	¼ gal.	10–75 lb.
Quantity of principal extinguishing agent produced.		20 gal.	2½ gal.	2½ gal.	Varies with contact with fire	Volume depends on handling
Nature of principal extinguishing agent.		Firefoam, a mass of bubbles filled with carbon dioxide	Liquid—soda-solution	Liquid—calcium chloride solution	Free gas—vaporized by heat of fire	Free gas
Principal extinguishing effect		Blanketing	Cooling	Cooling	Blanketing	Blanketing
Adapted for use on class of fires.	*A* Wood, textiles, rubbish, etc.	Yes	Yes	Yes	No	Yes
	B Oils, greases, etc.	Yes	No	No	Yes	Yes
	C Electrical machinery	No	No	No	Yes	Yes
	D Autos, trucks, etc.	No	No	No	Yes	Yes

TABLE 21.—FIRE-HAZARD PROPERTIES OF CERTAIN FLAMMABLE LIQUIDS, GASES AND SOLIDS

Based on Data Compiled by Committee on Flammable Liquids of the National Fire Protection Association*

Material	Flash point, °F.	Ignition temperature, °F.	Explosive limits per cent in air		Vapor density
			Lower	Upper	
Acetaldehyde	−17	365–716	4	57	1.52
Acetic acid	104–115	932			2.07
Acetic acid (glacial)	107–111	800–925	4		2.07
Acetic anhydride	110–141	600–675			3.52
Acetone	−4–36	932–1292	2–3	9–13	2.00
Acetyl chloride	40				2.71
Acetylene	Gas	763–959	2.5–3.2	52.2–82	0.90
Allyl alcohol	70–72	713	2.4–3.0		2.00
Aluminum paint	0–70				
Ammonia (anhydrous)	Gas	1204	16–16.1	25–27	0.59
Amyl acetate[4]	70–92	710–815	1.1		4.49
Amyl alcohol[2]	92–130	660–768	1.2–1.48		3.04
Aniline	79–183	987–1418			3.22
Anthracene	450	881 in O_2			1.15
Asphalt	400				
Benzaldehyde	144–148	356–377			3.66
Benzine	<0–5	475	1.1–2.6	4.8–5.9	4.48
Benzoic acid	250–268				4.21
Benzol[9]	−17–50	932–1364	1.4–3	4.7–8	2.77
Benzyl acetate	216				5.17
Benzyl alcohol	212	817			3.72
Benzyl chloride	140				4.36
Blast furnace gas	Gas		35	74	
Bromobenzine	149				5.41
Bronzing liquid	80				
Butane	Gas	805–1058	1.5–1.9	5.7–8.5	1.95
Butyl acetate	66–88	700–860	1.7–1.9		4.00
Butyl alcohol[2]	73–111	637–842	1.7	18.0	2.55
Butyl cellosolve	140–165				4.07
Butylene	Gas		1.7	9.0	1.94
Butyl ether—n	100				4.48
Butyl lactate	160				5.04
Butyraldehyde	<20–64				2.48
Butyric acid	170				3.04
Butyric anhydride	190				5.38
Camphor	125–180		0.61	3.5	5.24
Carbitol	210				4.62
Carbitol acetate	225				6.07
Carbon disulphide[11]	−40–4	212–338	1.0–4.1	50	2.64

* *Chem. Met. Eng.*, **47**, 31 (1940). Table from which these data were taken should be consulted for references to original literature sources.

Underwriters' Laboratories' Classification is standard for grading relative hazards of various flammable liquids. It is based upon the following scale: ether 100, gasoline 90–100, alcohol (ethyl) 60–70, kerosene 30–40, paraffin oil 10–20. [1]30–40, [2]40, [3]40–50, [4]55–60, [5]60–70, [6]70, [7]75, [8]75–80, [9]95–100, [10]100, [11]110.

TABLE 21.—FIRE-HAZARD PROPERTIES OF CERTAIN FLAMMABLE LIQUIDS, GASES AND SOLIDS.—(*Continued*)

Material	Flash point, °F.	Ignition temperature, °F.	Explosive limits per cent in air		Vapor density
			Lower	Upper	
Carbon monoxide	Gas	1177–1497	12.5–16.6	71.2–75	0.97
Carbon remover, liquid	<80				
Castor oil	487–505				
Cellosolve	111				3.10
Cellosolve acetate	127–142				4.72
Chlor benzol	81–102				3.88
Chloroethyl acetate	129–153				4.22
Cleaning solvents of kerosene class[1]	100–120	480–495	1.1	6.0	
Coal gas	Gas	1197–1200	5.3–8	19–31	
Coal-tar oil	<80				
Coconut oil	420–548				
Collodion	−25–0				
Corn oil	480				
Cottonseed oil (refined)	338–582	650–800			
Creosote oil	165	1022			
Cresol	177–187				3.72
Cresylic acid	110				
Croton aldehyde	55–127				2.41
Cumol	102–126				4.13
Cyclohexane	1		1.3	8.3	2.90
Denatured alcohol[6]	40–61	700–810	3.5	18.0	1.60
Diacetone	40–131				4.00
Dibutylphthalate	316–360				9.58
Dichlorethyl ether	172				4.93
Dichlorobenzene	153–172				5.07
Dichlorethylene	57–63	856	5.6–10	11.4–13	3.35
Diethylene glycol	286	444			3.66
Diethyl phthalate	284				7.66
Dimethylaniline	142–169	700–750			4.17
Dinitrobenzene	302				5.79
Dinitrochlorobenzene	369				6.98
Dioxan	65				3.03
Diphenylamine	307				5.82
Diphenylmethane	266				5.79
Dodecane	165		0.6		5.86
Ethane	Gas	950–1166	3.0–3.3	10.6–15.0	1.03
Ethyl acetanilide	126				4.72
Ethyl acetate	23–41	800–925	2.3–2.5	11.4–11.5	3.04
Ethyl acetoacetate	184				4.48
Ethyl alcohol[6]	48–90	700–1036	2.8–4.0	9.5–19.0	1.59
Ethyl benzene	59–61				3.66
Ethyl bromide		952	6–7	11	3.76
2-ethyl butyl alcohol	137				3.52
Ethyl cellosolve	104	460			3.10
Ethyl chloride	−37–0	966	3.6–4.3	11.2–15	2.22
Ethylene	Gas	1008–1110	3.0–4.2	14.1–35	0.97
Ethylene chlorhydrin	140				2.78

TABLE 21.—FIRE-HAZARD PROPERTIES OF CERTAIN FLAMMABLE LIQUIDS, GASES AND SOLIDS.—(*Continued*)

Material	Flash point, °F.	Ignition temperature, °F.	Explosive limits per cent in air		Vapor density
			Lower	Upper	
Ethylene diamine (anhydrous)	93				2.07
Ethylene dichloride[5]	57–70		6	16	3.42
Ethylene glycol	232–241	775–781	3.2		2.14
Ethyl ether[10]	−49–<20	356–649	1–3	5.2–48	2.56
Ethyl glycol	104				3.10
Ethyl lactate	115–117				4.41
Ethyl methyl ether	−35	374	2	10.1	2.07
Ethyl methyl ketone	30		1.97–2.0	10.2–12	2.41
Ethyl nitrate	50		3.8		3.14
Ethyl nitrite	−31	194	3	50	2.59
Ethyl propionate	54–60				3.52
Fish oil	150–420				
Flavoring extracts	<80				
Formaldehyde	90				1.03
Fuel oil	95–150				
Furfural	132–151	600–675	2		3.31
Gas oil	175–230	637			
Gasoline[9]	−45–20	500–570	1.3–1.4	6	3–4
Glycerin	349–350	650–932			3.17
Heptane	25–63	452–545	0.95–1.1	3.6–6	3.45
Hexahydrotoluol	25				3.38
Hexane	−24–0	479–909	1.1–1.3	4.2–6	2.97
Hexone	74				3.45
Hydrocyanic acid			5.6–12.75	27–40	0.9
Hydrogen	Gas	986–1143	4.1–9.5	66.5–80	0.069
Hydrogen sulfide	Gas	482–534	4.3–4.5	45.5–46	1.17
Hydroquinone	329				3.81
Illuminating gas	Gas	1094	5–7	21–31	
Kerosene[2]	81–140	482–563	1.1–1.2	6.0–7.0	4–8
Lacquer	0–80				
Lanolin	460				
Lard oil	398–600	650–750			
Lead tetramethyl			1.80		9.22
Linseed oil	378–662	650–750			
Liquid metal polish	<80				
Lubricating oil	392–608				
Methane	Gas	999–1452	4.9–6.2	12.7–16	0.55
Methyl acetate	3–40	850–953	4.1	13.9–14	2.56
Methyl acetoacetate	180				4.00
Methyl alcohol	30–90	800–900	6–7.8	18–36.5	1.11
Methyl amyl alcohol	114				3.52
Methyl bromide		999	13.5	14.5	3.27
Methyl cellosolve	105–107	551			2.62
Methyl cellosolve acetate	132				4.07
Methyl chloride	Gas	1170	8–8.3	17.2–19.7	1.74
Methyl cyclohexanone	118				4.86
Methyl cyclohexyl acetate	147				5.37

TABLE 21.—FIRE-HAZARD PROPERTIES OF CERTAIN FLAMMABLE LIQUIDS, GASES AND SOLIDS.—(*Continued*)

Material	Flash point, °F.	Ignition temperature, °F.	Explosive limits per cent in air		Vapor density
			Lower	Upper	
Methylene chloride		1224			2.93
Methyl ether	−42				1.59
Methyl formate		853–928	4.5–6	20–22.7	2.07
Methylhexalin	154				3.93
Methyl propionate	28				3.03
Methyl propyl carbinol	105				3.03
Methyl salicylate	219	850–950			
Monoethanolamine	200				2.10
Naphtha	−45–110	490–531	1.2	6.0	
Naphthalene	185–187	500 in O_2	0.9		4.42
Naphtha, petroleum	<80				
Naphtha ("solvent")	60	900	1.3	8.0	
Naphtha V.M. & P.	−40–30	500–520	1.2	6.0	
Naphthol, beta	307–322				4.97
Naphthylamine	315				4.93
Natural gas	Gas		4.8–5.0	13.5–15	
Nitrobenzene	188–198	900–950			
Nitrocellulose (wet with solvent)	40				
Nitrochlorobenzene	261				5.43
Nitrotoluol—para	223				4.72
Olive oil	419–505	650–800			
Paint, bronze or gold	0–70				
Paint, liquid	0–80				
Palm kernel oil	398				
Palm oil	323–421	600–752			
Paraffin oil	220–444				
Paraldehyde	63	410	1.3		4.55
Pentane	<0	593	0.25–2.5	4.5–7.5	2.48
Petrohol	59–66	845–895			
Petroleum ether[9]	−69–4	475–624	1.4	5.9	2.5
Phenol	172–174	1319			3.24
Phthalic anhydride	330				6.21
Pine oil, steam distilled	138–148				
Ponsolve[7]	49	835			
Propane	Gas	871–1090	2.0–2.4	7.0–9.5	1.52
Propyl acetate	58		2.0		3.52
Propyl alcohol, normal[4]	72–114	700–941			2.07
Propylene	Gas	927–952	2.0–2.2	9.0–9.7	1.45
Propylene dichloride	70				3.89
Propyl ether, iso	<32				3.52
Pyridine	68–80	900–1100	1.8	12.4–12.5	2.73
Pyroxylin solution	<80				
Rape oil	410–581				
Red oil, distilled	364				
Resorcinol	306				3.79
Rosin oil	257–270				
Soybean oil	566				

TABLE 21.—FIRE-HAZARD PROPERTIES OF CERTAIN FLAMMABLE LIQUIDS, GASES AND SOLIDS.—(*Continued*)

Material	Flash point, °F.	Ignition temperature, °F.	Explosive limits per cent in air		Vapor density
			Lower	Upper	
Sperm oil	428–486	586			
Tin tetramethyl			1.90		
Toluidine	185–202	900–1000			
Toluol[8]	35–86	986–1490	1.0–3.0	6.0–7.0	3.14
Triethanoamine	355				5.14
Tung oil	552				
Turpentine[3]	90–113	464–489	0.8		4.7
Turpentine substitute	90–110	480	1.2	6.0	4.0
Varnish	60–130				
Varnish shellac	40–70				
Vinyl chloride			4	22	2.15
Water gas	Gas		6–12.5	55–70	
Whale oil	455–515				
Xylene	76–122	900–1150	1.0–1.2	5.3–6.0	3.66

On all hose equipment, 2-in. and smaller, iron pipe thread is recommended unless other standards are already installed. This thread description is universally used and understood in all sections of the country and, since it is interchangeable with pipe threads, emergency and temporary repairs and extensions can easily be made with material obtained locally. Each municipal fire department has its own standard, although many cities are changing over to the proposed American Standard thread. Consequently, all 2½-in. hose for factory service should have the same thread as used by the city fire department, but in isolated plants, where city cooperation in case of fire cannot be expected, American Standard is recommended.

Size of Hose.—For inside protection, with an adequate water supply, a 1½- or 2-in. hose is recommended. These streams can easily be handled by the layman and will give sufficient volume of water to hold the average fire in check until the fire department arrives. If the supply is limited or is taken from a sprinkler-system supply pipe, 1¼-in. hose is recommended. If the pressure is adequate but the supply pipe is small, a 1-in. hose is better than nothing, but ¾-in. linen hose is worthless. For outside protection, for mill-yard service, a 2½ in. hose is recommended. A smaller hose will not give an adequate stream.

ILLUMINATION

Good illumination is important in all industrial plants, not only as an aid to quality and quantity of production,[1] but also from the standpoint of safety, workers' comfort and health.[2] Daylight is not dependable. A survey made in Cleveland, Ohio, over a period of 29 years, during the 24 hours of the day, showed a considerable variation in the hours of sunshine, cloudiness and darkness, from month to month. The averages of these data are plotted in Fig. 35.

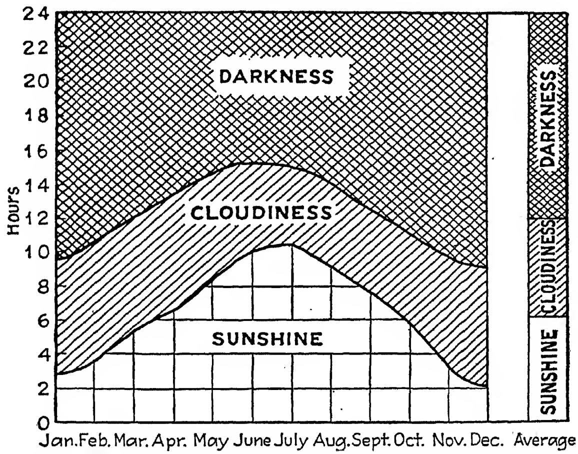

FIG. 35.—Average variation in hours of sunshine, cloudiness, and darkness during 24-hr. period at Cleveland, Ohio. Summary of 29 annual records. (*Ind. Eng.*, July, 1927.)

Every plant needs artificial light, whether or not any night work is done. In December, for example, there are on the average only 2 hours of sunlight per day. There should, of course, be an even working light for all the day. In a plant well lighted by daylight above, the illumination on a cloudy day drops from 40 or 50 ft.-candles to 3 or 4. The changed intensity is noticeable in increased spoilage and accidents and in lowered production. When the days are short, accidents increase in poorly lighted

[1] HARRISON, W., *Chem. Met. Eng.*, **25**, 407 (1921).

[2] Chemical Plant Lighting, *Chem. Met. Eng.*, **47**, 25–32 (1940).

plants. With good artificial lighting, the winter peak of accidents is reduced and the average for the whole year is considerably decreased. It is pointed out that approximately 15 per cent of all industrial accidents may be traced to poor lighting. Improved lighting increases speed and accuracy of vision, improves morale, improves supervision, reduces labor turnover, provides uniform working conditions throughout the day, reduces accidents, improves health and increases production.

Natural Illumination.—Natural illumination may be obtained through the medium of windows in the side walls, in monitors or in skylights. Lighting from above is generally better than from sidelights; this should be provided for wherever practicable. Skylights in the roof may be individual skylights, or they may be provided through sawtooth roof construction. Sawtooth construction permits nearly uniform illumination over the entire floor area. When side windows are used, uniform lighting is well-nigh impossible; and shades or deflectors are necessary to intercept or diffuse the direct rays of the sun. Prismatic glass is recommended by the American Standard Lighting Code for the upper sash of windows.

Fundamentals of Good Lighting.[1]—The chemical engineer should understand the fundamentals of good lighting and other economic facts relating to lighting to guide him in the design of his assembled plant.

The six fundamental requirements of a good lighting system can be summarized briefly as follows:

1. A steady light of sufficient intensity on all working planes.
2. A comparable intensity on adjacent areas and side walls.
3. Light of a color and spectral character suited to the work.
4. Freedom from glare and from glaring reflections.
5. Light diffused and directed so as to eliminate objectionable shadows and bad contrasts.
6. The system must be simple, reliable, easy of maintenance and suitably economical in initial and operating cost.

[1] Marks, L. S., "Mechanical Engineers' Handbook," 4th ed. pp. 1692–1713, McGraw-Hill Book Company, Inc., New York, 1930; Adequate information and desirable practices are included in the publication, "Code of Lighting, Factories, Mills and Other Work Places," U. S. Government Printing Office, Washington, D. C., and "State Requirements for Industrial Lighting," *U. S. Department of Labor, Women's Bureau, Bull.* 94, 1932.

Lighting Equipment.—Lighting fixtures consist of:

1. Reflectors (dome, bowl, cone, symmetrical angle, elliptical angle, socket, shade holder, vaporproof, weathertight, half shades, ceiling fixtures, wall fixtures, enclosed fixtures).
2. Lamp holders (angle and twin sockets, porcelain, socket receptacles, cluster bodies, socket extensions, cleat sockets, etc.).
3. Floodlight projectors.
4. Lamps.
5. Cord.
6. Conduit.
7. Armored cable.
8. Switches.
9. Boxes.
10. A large number of miscellaneous appliances.

The specification of this lighting equipment and its installation are the functions of the illuminating engineer.

Emergency Lighting.—Since failure of lighting at a critical time, as at the outbreak of a fire, might easily contribute to serious loss of life in a factory with many employees, because of difficulty in finding exits in a dark, smoke-filled room, a number of communities require installation of an independent system for emergency lighting. This is an excellent provision in any medium-sized or large plant. Such a system should have separate circuits and be fed from a source separate from that normally supplying the lighting. If the plant has its own powerhouse, the emergency lighting should be fed from a central station or other external source. If the plant uses central-station power, a separate service should furnish the emergency lighting. This lighting should include all exit and stairway lights and enough special lights on each large floor to permit finding the way to the nearest exit.

Floodlighting.—Floodlighting is resorted to for dangerous places or where large areas are to be lighted, wherein moving objects constitute a danger to life or limb. The use of the Cooper-Hewitt mercury-vapor lamp is desirable in those plants where eyestrain is great.

Illumination Requirements.—In laying out the lighting circuits, the illumination requirements of the different rooms must first be known. These depend on the kind of work done, the size and light-absorbing conditions of the room and the nature of the lighting equipment selected. On account of the variables,

the power consumption for lighting ranges from 0.5 to 2.5 watts per square foot in different departments of different plants. For any chosen lighting intensity and related conditions, it is possible to find the corresponding unit watt consumption. Assume it to be 1.2 watts per square foot. The floor area in square feet multiplied by 1.2 will then give the total wattage to be provided for the room in question. Not more than 660 watts is allowed on ordinary lighting circuits. From these facts it is possible to lay out the requisite circuit, the arrangement of which in a

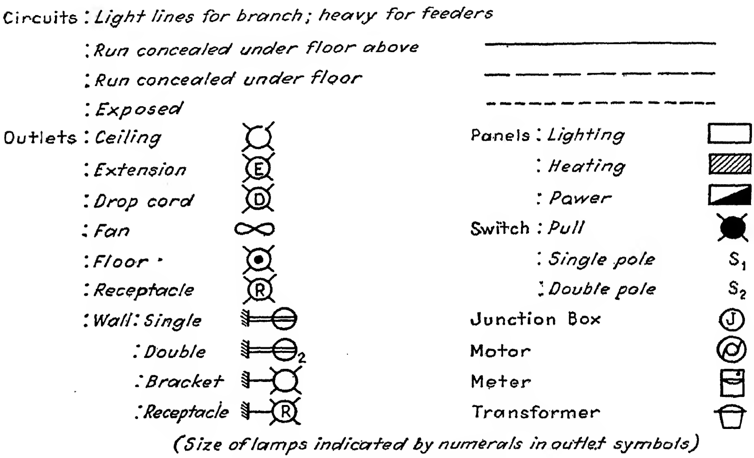

FIG. 36.—Electrical symbols.

large room should usually permit switching on the lamps in rows parallel to the windows, so that those farthest from the windows may be turned on first. Symbols to use in design for electrical equipment are given in Fig. 36.

A compilation of illumination requirements including glare classification, limitation of light-source glare, mounting heights of lighting units, room index for narrow and average rooms for direct and indirect lighting, guide to the selection of reflecting equipment and coefficients of utilization, lumen output of multiple Mazda lamps and other general information is presented by Warner and MacNamara.[1]

[1] PERRY J. H., "Chemical Engineers' Handbook," pp. 2691–2697.

Illumination in Chemical Plant Design.—The design of a chemical plant calls for proper lighting at strategic points near equipment, where physical and chemical hazards exist, as well as at localized points where lights are needed to enable the operator to make observations and adjust controls more accurately. The spotting of the outlets or location of desired points of illumination cannot be entrusted entirely to the illuminating engineer. Rather, the chemical engineer must assist him, indicating where the greatest need for illumination exists, by reason of operating needs. Each chemical engineering plant is a specialized case and needs specialized treatment.

Details of location for conduits, complete code specifications and other such details are the responsibility of the illuminating engineer. Types of switches, outlets, lights and reflectors are chosen by him only after consultation with the chemical engineer relative to the health, mechanical, chemical and fire hazards incidental to the processing.

The design of a complete factory-illumination layout for a chemical plant is not a difficult task with standard factory electrical equipment. Pamphlets issued by manufacturers of electrical equipment, containing specifications, details, codes and quotations, are available and serve as excellent guides to the designing chemical engineer. Conventional symbols (see Fig. 36) for indicating various pieces of electrical equipment should be used in all sketches submitted to the illuminating engineer by the chemical engineer to convey to the former the requirements for the chemical plant.

Specific Illumination Requirements.—In chemical plants, where usually 24-hr. processing is the rule, the need for artificial light becomes apparent. Table 22 gives the illumination requirements for a large number of chemical engineering plants and operations.

Operating Costs.—Operating lighting expense includes cost of electricity and of lamp replacements. Most lighting installations range in operating time from 0 hr. in June to 8 hr. per day in December, averaging 4 hr. per day for the year. Some installations operate 8 hr. per day for the year. Some installations operate 8 hr. per day per shift for the entire year, while the average time of burning per month consists of 25 days. Ascertain the lighting rate for electricity; multiply the kilowatt

TABLE 22.—RECOMMENDED STANDARDS OF ILLUMINATION FOR INDUSTRIAL INTERIORS[1]

(These values represent order of magnitude rather than exact levels)

	Foot-candles
Aisles, stairways, passageways	2
Assembly:	
Rough	10
Medium	20
Fine[2]	50–100
Extra fine[2]	100 or more
Automobile manufacturing:	
Assembly line[2]	50–100
Frame assembly	15
Body manufacturing:	
Assembly	20
Finishing and inspecting	100 or more
Bakeries	20
Book binding:	
Folding, assembling, pasting, etc.	10
Cutting, punching and stitching	20
Embossing	20
Breweries:	
Brew house	5
Boiling, keg washing and filling	10
Bottling	15
Candymaking	20
Canning and preserving	20
Chemical works:	
Hand furnaces, boiling tanks, stationary driers, stationary and gravity crystallizers, mechanical furnaces, generators, stills	5
Mechanical driers, evaporators, filtration, mechanical crystallizers, bleaching	10
Tanks for cooking, extractors, percolators, nitrators, electrolytic cells	15
Clay products and cements:	
Grinding, filter presses, kiln rooms	5
Molding, pressing, cleaning and trimming	10
Enameling	15
Color and glazing	20
Cloth products:	
Cutting, inspecting, sewing:	
Light goods	20
Dark goods[2]	100 or more
Pressing, cloth treating (oil-cloth, etc.):	
Light goods	10
Dark goods	20
Coal:	
Breaking, washing and screening	5
Construction—indoor:	
General	10
Dairy products	20
Elevators:	
Freight and passenger	10
Engraving[2]	100 or more
Forge shops and welding	10
Foundries:	
Charging floor, tumbling, cleaning, pouring and shaking out	5
Rough molding and coremaking	10
Fine molding and coremaking	20
Garages—automobile:	
Storage—live	10
Dead	2
Repair department and washing[2]	30–50
Glassworks:	
Mix and furnace rooms, pressing and lehr, glass blowing machines	10
Grinding, cutting glass to size, silvering	20
Fine grinding, polishing, beveling, etching and decorating[2]	30–50
Inspection[2]	50–100
Glove manufacturing:	
Light goods:	
Cutting, pressing, knitting, sorting	10

TABLE 22.—RECOMMENDED STANDARDS OF ILLUMINATION FOR INDUSTRIAL INTERIORS.[1]—(*Continued*)

	Foot-candles
Stitching, trimming and inspecting	20
Dark goods:	
Cutting, pressing, knitting, sorting	20
Stitching, trimming and inspecting[2]	100 or more
Hangars—airplane:	
Storage—live	10
Repair department[2]	30–50
Hat manufacturing:	
Dyeing, stiffening, braiding, cleaning and refining:	
Light	10
Dark	20
Forming, sizing, pouncing, flanging, finishing and ironing:	
Light	15
Dark	30
Sewing:	
Light	20
Dark[2]	100 or more
Ice making—engine and compressor room	10
Inspection:	
Rough[2]	10
Medium[2]	20
Fine[2]	50–100
Extra fine[2]	100 or more
Jewelry and watch manufacturing	100 or more
Laundries and dry cleaning	20
Leather manufacturing:	
Vats	5
Cleaning, tanning and stretching	10
Cutting, fleshing and stuffing	15
Finishing and scarfing	20
Leather working:	
Pressing, winding and glazing:	
Light	10
Dark	20
Grading, matching, cutting, scarfing, sewing:	
Light	20
Dark[2]	100 or more
Locker rooms	5
Machine shops:	
Rough bench and machine work	10
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	20
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing[2]	50–100
Extra fine bench and machine work, grinding—fine work[2]	100 or more
Meat packing:	
Slaughtering	10
Cleaning, cutting, cooking, grinding, canning, packing	20
Milling—grain foods:	
Cleaning, grinding and rolling	10
Baking or roasting	20
Flour grading	30
Offices:	
Private and general:	
No close work	10
Close work	20
Drafting rooms	30
Packing and boxing	10
Paint manufacturing	10
Paint shops:	
Dipping, spraying, firing	10
Rubbing, ordinary hand painting and finishing	20
Fine hand painting and finishing[2]	50–100
Extra fine hand painting and finishing (automobile bodies, piano cases, etc.)[2]	100 or more

TABLE 22.—RECOMMENDED STANDARDS OF ILLUMINATION FOR INDUSTRIAL INTERIORS.[1]—(*Continued*)

	Foot-candles
Paper box manufacturing:	
Light	10
Dark	20
Storage and stock	5
Paper manufacturing:	
Beaters, grinding, calendering	10
Finishing, cutting, trimming	20
Plating	10
Polishing and burnishing	15
Power plants, engine rooms, boilers:	
Boilers, coal and ash handling, storage battery rooms	5
Auxiliary equipment, oil switches and transformers	10
Switchboards, engines, generators, blowers, compressors	15
Printing industries:	
Matrixing and casting	10
Miscellaneous machines	15
Presses and electrotyping	20
Lithographing[2]	50–100
Linotype, monotype, typesetting, imposing stone, engraving[2]	50–100
Proofreading[2]	100 or more
Receiving and shipping	10
Rubber manufacturing and products:	
Calenders, compounding mills, fabric preparation, stock cutting, tubing machines, solid tire operations, mechanical goods building, vulcanizing	10
Bead building, pneumatic tire building and finishing, inner tube operation, mechanical goods trimming, treading	20
Sheet metal works:	
Miscellaneous machines, ordinary benchwork	15
Punches, presses, shears, stamps, welders, spinning, medium benchwork	20
Tin plate inspection[2]	30–50
Shoe manufacturing:	
Hand turning, miscellaneous bench and machine work	10
Inspecting and sorting raw material, cutting and stitching:	
Light	20
Dark[2]	100 or more
Lasting and welting	20
Soap manufacturing:	
Kettle houses, cutting, soap chip and powder	10
Stamping, wrapping and packing, filling and packing soap powder	20
Steel and iron mills, bar, sheet and wire products:	
Soaking pits and reheating furnaces	5
Charging and casting floors	10
Muck and heavy rolling, shearing, rough by gage, pickling and cleaning	10
Plate inspection and chipping[2]	30–50
Automatic machines, light and cold rolling, wire drawing, shearing, fine by line	15
Stone crushing and screening:	
Belt conveyor tubes	5
Main line shafting spaces, chute rooms, inside of bins	5
Primary breaker room, auxiliary breakers under bins	5
Screens	10
Storage battery manufacturing:	
Molding of grids	10

TABLE 22.—RECOMMENDED STANDARDS OF ILLUMINATION FOR INDUSTRIAL INTERIORS.[1]—(*Continued*)

	Foot-candles
Store and stock rooms:	
Rough bulky material	2
Medium or fine material requiring care	10
Structural steel fabrication	10
Sugar grading	30
Testing:	
Rough	10
Fine	20
Extra fine instruments, scales, etc.[2]	100 or more
Textile mills:	
Cotton:	
Opening and lapping, carding, drawing, roving, dyeing	10
Spooling, spinning, drawing-in, warping, weaving, quilling, inspecting, knitting, slashing (over beam end)	20
Silk:	
Winding, throwing, dyeing	15
Quilling, warping, weaving, finishing:	
Light goods	15
Dark goods	30
Woolen:	
Carding, picking, washing, combing	10
Twisting, dyeing	10
Drawing-in, warping:	
Light goods	15
Dark goods	30
Weaving:	
Light goods	15
Dark goods	30
Knitting machines	20
Tobacco products:	
Drying, stripping, general	10
Grading and sorting[2]	100 or more
Toilet and washrooms	5
Upholstering:	
Automobile, coach, furniture	20
Warehouses	5
Woodworking:	
Rough sawing and bench work	10
Sizing, planing, rough sanding, medium machine and benchwork, gluing, veneering, cooperage	20
Fine bench and machine work, fine sanding and finishing	30

[1] Plant Operation Library, *Factory Management and Maintenance*, **94**, 301 (1936).

[2] Illumination of this order may in some instances be provided from a general lighting system. In other cases it will be found more economical to provide a combination of general plus supplementary lighting. Direction of light, diffusion, eye protection, study of direct and reflected glare, as well as elimination of objectionable shadows are all vitally important and must be considered.

connected load, by burning hours per month, by rate per kilowatt-hour, to obtain the average cost of electricity per month. The average burning hours of a lamp are 1,000. Multiply the total cost of lamps by the average hours per month, divided by 1,000, to get cost of lamp replacements per month.

Painting.—Paint is considered as part of the fundamental design of plant illumination. Painted surfaces are essential aids in reflecting light, the reflection depending chiefly on the

TABLE 23.—LIGHT REFLECTIVE VALUE OF COLORED PAINTS[1]

Color	Per cent light reflected	Color	Per cent light reflected
White	82–89	Light wood (tan)	42–49
Cream	73–78	Gray	36–61
Ivory	62–80	Light blue	34–61
Buff	61–75	Pink	30–46
Aluminum	65	Dark tan	17–63
Light green	49–66	Brown wood	17–29
Yellow	48–75	Dark red	13–30
Dark green	11–25		

[1] GARDNER, H. A., *Factory Management and Maintenance*, **92**, 104 (1934).

ceiling and upper part of the walls. Gardner has given light reflective values of colored paints, as shown in Table 23.

VENTILATION AND HEATING

Ventilation.—Ventilation may be defined as the process of causing fresh air to circulate through the space to be ventilated, replacing simultaneously the foul air removed. Any ventilation system, to be successful in its purpose, must, therefore, maintain certain predetermined quantitative standards of air movement within the space to be ventilated. It must also be capable of removing stale air, odors, fumes, dust, smoke and vapors from all parts of the ventilated area. In addition, it must take into account temperature and humidity. The need for such removal is highly urgent in chemical industrial plants. Wherever human beings live or labor indoors, there is a positive need for ventilation as a protection to health and an assurance of alertness. (See Marks' "Mechanical Engineers' Handbook," pp. 1636–1679, 4th ed.)

A continuous supply of pure air is no doubt of greater importance from the standpoint of maintenance of health than it is from the standpoint of prevention of accidents, but the two are related. Whatever lowers the vitality of the workman decreases his alertness and watchfulness in avoiding accidents. Impure air, gases, vapors, dust and smoke, therefore, all increase the chance of accident, in addition to imperiling the health of the workmen. Many states have codes governing ventilation of certain industries, and these codes must be complied with

before operations are permitted. Some cities have adopted additional codes.

Ventilation Systems.—There are two types of ventilating systems, the systematic and nonsystematic. The systematic is the controllable kind and the only one recommended for chemical plants, when climatization is important. Ventilation can be accomplished most effectively and positively in industrial plants by roof ventilators or by suction- or pressure-duct systems for withdrawal or forcement of air into the building.

Air Purification and Temperature and Humidity Control.—Air in many chemical plants must be washed to give it the desired standard of purity; in addition, conditions of operation may require a close control of temperature and humidity. Humidification, *i.e.*, the addition of moisture, is accomplished in a device known as an air washer or humidifier, consisting of spray nozzles through which water is projected to wash the air, the water being heated to the temperature necessary to give the air the desired moisture content. Dehumidification is accomplished by cooling the air by mechanical refrigeration, by refrigerated spray water in air washers, or by natural cooling water in coils. The Cooling Tower Company, the Carrier Engineering Company and other manufacturers publish considerable data on air-purification and temperature- and humidity-control apparatus. Complete air conditioning, according to the American Society of Heating and Ventilating Engineers, consists of (1) control of temperature, humidity, rate of air flow and direction of air flow; and (2) removal of impurities. (See Marks' "Mechanical Engineers' Handbook," pp. 1680–1692, 4th ed.)

Dust and fume removal are quite common problems in the chemical industries. Fume ducts, flues, fans and ventilators usually require special protective coatings or must be constructed of special metals to resist the chemical fumes handled.

Air Requirements.—Experiments by ventilation engineers over a number of years have determined the approximate air changes necessary each hour in average rooms and buildings, if effective ventilation is to be secured. It has been proved that approximately 2,700 cu. ft. of fresh air is required by the average person each hour, and scores of ventilation specifications have been based on that estimate. Still, the use of this factor as a uniform basis is dangerous for it does not take into account

the devitalization of air by machinery and manufacturing processes.

Smoke, fumes and vapors caused by engines, furnaces, vats or any other manufacturing processes render useless a great portion of the fresh air brought in. Still more air is expended in forcing these elements out of the building. While each ventilation setup usually involves special problems necessitating individual consideration, it has been found that under many

Table 24.—Recommended Air Changes[1]

Building	Exhaust	
	Cubic feet per minute per occupant	Minimum number of air changes per hour
Assembly and convention halls	30	8
Boiler rooms	......	10
Churches	20	8
Contagious-disease hospitals	80–100	.....
Engine rooms	......	8–10
Factories	20–30	4
Foundries	......	4
Garages	......	12
Laboratories	......	8
Kitchens	......	10
Pump rooms	......	4–6
Machine shops	......	4–6
Paper mills	......	10–20
Dye houses	......	10–20
Paint shops	......	10–15
Hospitals	70–80	.....
Laundries	......	10
Libraries	......	5
Mill buildings	20–30	4
Offices	20–30	6
Public toilets	......	10
Public waiting rooms	......	6
Schools	40	8
Theaters	30	8
Bakeries	......	10
Forge shops	......	10
Galvanizing plants	......	20–30
Pickling plants	......	10–15

[1] Allen Corporation.

conditions the frequency of air changes listed in Table 24 can be safely used. Data given in the table are based on average weather conditions in temperate climates. Where extreme hot or cold weather predominates, these figures are subject to some revision.[1]

Heating.—There are two kinds of heating required in chemical plants: (1) that for processing, and (2) that for maintenance of proper living conditions in the plant. In general, processing utilizes low-pressure steam on evaporators and reaction kettles, and high pressure only where high temperatures are desired. The heating of an industrial plant can be tied into the processing system, but more often it is separately controlled and maintained. (See Marks' "Mechanical Engineers' Handbook," pp. 1636–1679.)

Heating-system Types.—The sources of heat in a plant may come from the heating system, or from persons in the building, motors, lights, machinery and processing equipment. The last source must be considered in determining the heat requirements of a plant when the equipment has not been insulated to prevent heat losses. The problem of heat requirements necessarily depends upon the processing carried out in the plant. Types of heating include:

A. Hot air.
   1. Open grates.
   2. Fireplace heaters.
   3. Stoves.
   4. Hot air (pipeless and trunk piping).

B. Hot water.
   1. Gravity.
   2. Low pressure.

C. Steam.
   1. One-pipe vacuum system.
   2. Two-pipe vacuum system.
   3. Two-pipe vapor system.
   4. Weather-compensating system.

D. Hot-blast and unit heating.
   1. Low velocity.
   2. High velocity.
   3. Blanket or air strata.

[1] For complete information on ventilation requirements and standards see "Regulation for Installation of Blower and Exhaust Systems," National Board of Fire Underwriters; also Safe Practices Pamphlets, 32 and 37, National Safety Council, Chicago, Ill.

Hot-air Systems.—The centralized hot-air furnace is a large stove encased in brick or sheet steel, having an air duct or cold-air tube through which air from the outside of the building is heated and introduced into the room. Distribution of the hot air from the furnace to the distant parts of the building is accomplished by fans, through pipes, and adjusted by central registers and dampers. For chemical plants this type of heating is not so desirable as hot water or steam, since the latter may be tied into the processing system in the plant.

Hot-water System.—The hot-water system for heating the building may use radiators of the pipe, stand or suspended forced-air types. In the *gravity system,* circulation is maintained by the difference in density between the hot water entering the radiators and the cooler water leaving. A supply pipe from the furnace connects with the intake of each radiator and also with an expansion tank at the highest point in the system. Return lines pitch downward slightly on horizontal runs and return to the bottom of the furnace. Since distribution depends upon the difference in temperature in the exit and inlet parts of the heater, the rate of flow is controlled in a measure by the amount of radiation of heat from the system. In cold weather the faster cooling of the radiators causes a more rapid flow of water than when the weather is mild. Hence, this system can be called a compensating system; its action is slow.

In the *low-pressure system,* a centrifugal pump forces the water through the system; quick pickup can be accomplished by changing the speed of the pump. By installation of a thermostatic device that controls the speed or operation of the pump, this system can become weather compensating.

Based upon square feet of exposed wall surface the square feet of radiation required for hot-water systems is one-tenth the value of the exposed wall surface.

Steam Heat.—In the *one-pipe* steam-heating system the radiator connections carry both steam and condensate. The supply main (which also serves as the return) is pitched downward from a point above the furnace, following a course depending upon the location of the radiators to be supplied. The pitch should not be less than ¾ to 1 in. in 10 ft. Depending upon the contour of the building, the mains may be carried to some distant point from the boiler before terminating or they may be

arranged so that their terminus occurs at or near the boiler. In either case, the main return is dropped below the water line of the boiler, with a check valve at the base of the drop to prevent water from the boiler surging into the system. The installation of air and vacuum valves and correlated devices on one-pipe steam-heating systems overcomes certain inherent weaknesses. The valves function to eliminate air rapidly from the system and seal it against further intrusion of air when the steam pressure drops. Furthermore, they keep the system under a vacuum between heating-up periods and also serve to eliminate noises and pounding on account of steam and condensate traveling in opposite directions in the same piping.

The standard *vacuum system* of heating is a *two-pipe* system wherein it is necessary mechanically to create a vacuum on the return line by means of a steam- or electrical-driven vacuum pump, which purges the system of air, thereby reducing the pressure in the return lines and returning the condensate to the boiler. The system may be designed upfeed or downfeed, *i.e.*, to supply the radiators with steam from mains in the basement, or by carrying a main riser to the attic and from there supplying the radiators with downfeed risers.

The ability to generate heat as it is needed to meet outside weather conditions, with a minimum amount of fuel and attention, with maximum efficiency and utmost simplicity, constitutes the appeal of the *two-pipe vapor system,* which circulates vapors at very low pressures and is silent in operation. Vapor can be generated at as low as 4 oz. pressure and still circulate sufficient vapor throughout the supply system to produce a radiator-heat output that corresponds directly to heat demand in mild weather. Such a system can be operated to meet sudden demands for more or less heat as outside weather conditions change. The amount of vapor delivered to the radiators can be controlled by regulating the opening of the radiator valves, which automatically controls a sensitive damper regulator on the generating unit, closing or opening the drafts as weather conditions demand.

Vapor-system units eliminate air binding and the necessity of an air valve on each radiator, require a lower initial pressure to achieve circulation, make the system noiseless, assure safety, permit minimum sizes of piping and avoid complexity of design. This system is applicable to the most serious heating problem.

The *compensating system* of heating accomplishes its results by compensating the volume and the temperature of the steam in the entire heating system and by limiting the amount of steam which each radiator can consume—all in accordance with weather requirements. This eliminates the waste of heat that results when a window is permitted to remain open more than is required for ventilation, or where one part of a building requires more heat than another. The weather-compensating system is a two-pipe vacuum system similar in most points to the ordinary return-line vacuum system, using a vacuum pump to create circulation and to withdraw condensate from the system and return it to the boiler or steam-supply unit. In the main supply system is placed a compensating supply control which can be operated manually, semiautomatically or fully automatically, by thermostat, as desired. This control governs the pressure (or vacuum) and regulates the quantity and temperature of the steam distributed throughout the system.

Hot-blast and unit heating systems force or draw air by means of a fan over a series or arrangement of pipes in small units, heated by steam, hot water or gases, the air being drawn from the outside, or recirculated in the room, depending upon the heating units. Hot-blast and unit heaters may be used for complete, self-contained heating or heating and ventilating plants, which distribute heat uniformly without the use of ducts.

TABLE 25.—HEAT-TRANSFERENCE TABLES FOR BLOWER HEATING[1]
(B.t.u. delivered by 1 cu. ft. of air cooling from discharge-outlet temperature to temperature inside building)

Outlet temperature, °F.	Temperature inside building, °F.			
	80	70	65	60
180	1.503	1.653	1.728	1.803
160	1.241	1.396	1.473	1.550
140	0.961	1.121	1.202	1.281
130	0.815	0.977	1.059	1.140
120	0.663	0.828	0.911	0.994
110	0.506	0.674	0.758	0.842
100	0.343	0.515	0.600	0.686
90	0.175	0.349	0.436	0.524

[1] American Radiator Co.

They afford positive ventilation and easy regulation. The heating units are completely assembled and built in sizes to meet the requirements. Unit heaters have in some cases been used instead of the central-fan system for both heating and ventilating. Such installations may be considered good practice, but sound engineering demands a careful comparison of the advantages and disadvantages of these two types of fan heating, as well as a comparison of the relative costs before a decision is made.

There are only two ways to apply ordinary unit heaters to the problem of heating an industrial building. One is the *displacement* method and the other is the *mixture* method. With the first method, cool intake air is drawn from the floor by the fans of the unit, and warm outlet air projected over the breathing area by the unit. The stratum of cool air taken in from the floor level is replaced by the air above it, which descends as it cools. Applying unit heating with ordinary unit heaters of the suspended type is done by what is known as the *mixture* method. The velocity of the warm outlet air issuing from a suspended type unit must be great enough to mix this air with the cooler air down at the floor level. Data on forced-draft heating are given in Tables 25 and 26.

TABLE 26.—FACTORS FOR CONVERTING AIR VOLUME AT DISCHARGE-OUTLET TEMPERATURE TO EQUIVALENT AIR VOLUME AT 140°F. AND AT 70°F.[1]

Outlet temperature, °F.	Outlet temperature, °F.	
	140	70
180	0.938	0.828
160	0.968	0.855
140	1.000	0.883
130	1.017	0.898
120	1.035	0.914
110	1.053	0.930
100	1.072	0.946
90	1.091	0.964

[1] American Radiator Co.

Radiation Losses.—In order to heat a building properly, a given amount of radiation is installed to compensate for the heat lost through the walls, windows, doors and cracks into the

outside atmosphere. This quantity of radiation is carefully calculated to meet the severest weather conditions likely to be encountered and thus to maintain a comfortable temperature within the building.

The U. S. Weather Bureau publishes data on temperatures for various localities throughout the United States (see Perry's "Chemical Engineers' Handbook," pp. 126–127). It states that heat is required 210 to 240 days out of the entire year, depending upon the locality. Of this period weather reports indicate that but 5 per cent is subjected to severe weather conditions demanding a maximum heat load, while heat may be supplied well under maximum heat load for the remaining 95 per cent of the period.

Heating Requirements of Factory Buildings.—The quantity of heat required in an industrial plant depends on the nature of the work. For example, if a high humidity is maintained, as in a textile plant, lower temperatures can be carried than where the atmosphere is quite dry. Where workmen are actively moving about, much lower temperatures are required than where the workers, such as rayon inspectors, are sitting down at workbenches. Table 27 lists the temperature that should be maintained in various rooms and various industrial buildings.

TABLE 27.—BUILDING AND ROOM TEMPERATURES[1]
(For outside temperature of 0°F.)

	°F.		°F.
Showers	85	Textile mills	65
Offices	70	Foundries	50–60
Hospitals	72–75	Boiler shops	50–60
Paint shops	80	Machine shops	60–65
Woodworking shops	60–65	Shoe factories	68–72
Clothing shops	70	Factories in general	65

[1] American Radiator Co.

A mean temperature of 68°F. inside the building is comfortable and healthful. Outside temperature controls the inside and may be predicted from local records. The heat supplied in the building is lost by radiation from the building surfaces, and by replacement by cold air from outside (infiltration).

TABLE 28.—BUILDING HEATING (RADIATION PLUS INFILTRATION)[1]
(Radiation: square feet building surface heated; 0°F. outside, 60°F., inside)

Type of Surface	B.t.u. per Hour Lost per Square Feet Surface
Glass, windows and doors	55
Glass, skylight	75
12-in. brick wall	16
12-in. brick and plaster	14.5
8-in. plain concrete	30
Corrugated iron, loose	83
Corrugated iron, tight	62
Frame, standard	12
Frame, no lath or plaster	17.5
Roof, tongue and groove on 1-in. boards	15
Roof, tongue and groove on 4-in. concrete	30
Roof shingles on sheeting	20
Floors, concrete on earth	7.75
Floors, wood on sills	3.25
Infiltration. lineal feet heated, at 5 m.p.h. wind velocity	Per Lineal Foot
Wood sash, fixed	23
Wood sash, double-hung	45
Steel sash, double-hung, Fenestra, double doors	9
Outside doors	18

[1] American Radiator Co.

Table 28 shows the unit losses for various building surfaces, from which the quantity of radiation may be calculated. It is a convenient table for calculating heating requirements for factory buildings. A fair idea of the quantity of radiation surface may

TABLE 29.—SOURCES OF INTERNAL HEAT[1]

	B.t.u. per Hour
1 horsepower	2,546.0
1 kilowatt	3,415.0
100-watt lamp	341.5
1 man at rest	400.0
1 man at work	500.0
1 cu. ft. producer gas	150.0
1 cu. ft. illuminating gas	550.0–700.0
1 cu. ft. natural gas	1,000.0

NOTE.—Welsbach burner consumes 3 cu. ft., and fishtail, 5 cu. ft. gas per hour.

[1] American Radiator Co.

be obtained by assuming 1 sq. ft. of radiation per 160 cu. ft. of mill interior, assuming that the structure is adapted to the climate. Table 29 lists some common sources of internal heat, and Table 30 includes the data on the number of B.t.u. required for heating air through definite temperature intervals.

TABLE 30.—B.T.U. REQUIRED FOR HEATING AIR[1]
(Quantity of heat in B.t.u. required to raise 1 cu. ft. of air through any given temperature interval)

Outside tempera-ture, °F.	Temperature of air in room, °F.									
	40	50	60	70	80	90	100	110	120	130
−40	1.824	2.052	2.281	2.509	2.738	2.967	3.197	3.424	3.654	3.882
−30	1.559	1.782	2.005	2.229	2.452	2.675	2.899	3.125	3.346	3.570
−20	1.306	1.524	1.742	1.960	2.179	2.397	2.615	2.834	3.053	3.271
−10	1.065	1.278	1.491	1.704	1.918	2.132	2.345	2.558	2.772	2.986
0	0.833	1.042	1.250	1.459	1.668	1.877	2.085	2.294	2.504	2.713
10	0.612	0.817	1.020	1.224	1.428	1.633	1.837	2.042	2.246	2.451
20	0.399	0.599	0.799	0.999	1.199	1.399	1.599	1.800	2.000	2.200
30	0.196	0.391	0.587	0.783	0.977	1.175	1.371	1.567	1.764	1.960
40	0.000	0.192	0.384	0.576	0.768	0.960	1.152	1.344	1.537	1.729
50	.....	0.000	0.188	0.376	0.565	0.753	0.941	1.130	1.319	1.507
60	.....	.....	0.000	0.185	0.369	0.554	0.739	0.924	1.108	1.293
70	.....	.....	.....	0.000	0.181	0.362	0.544	0.725	0.906	1.088

[1] American Radiator Co.

For outside walls, excluding floors and roofs, quantities of radiation should be increased for wind; for instance, the factor for New York City is 50 per cent, while for Salt Lake City, where wind is usually light, the factor is 10 per cent. Infiltration is proportional to wind velocity.

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CHAPTER VII

POWER AND POWER TRANSMISSION

The chemical engineering industries are the largest users of electrical power equipment among the industries today. This is due to the modern demand for extreme flexibility, a demand which sometimes errs on the side of too many individual drives in cases where the group-shafting system would be more economical. Practically all modern chemical equipment, such as high- and low-pressure mixing vessels, driers, high-speed pulverizers and attrition mills, must be driven. All such equipment can be propelled either by individual electric motors or by systems of belting, shafting and gearing.

Sources of Power.—Power can be obtained from coal, gas, water, oil, wood or windmills. The fuels (generally coal), however, supply the most flexible and economical source, inasmuch as they provide for generation of steam both for processing and for electricity production. Power can be economically developed as a by-product in most chemical plants, if the needs are great enough, since the process requirements generally call for low-pressure steam. The turbines or engines used to generate electricity can be operated noncondensing and supply exhaust steam very valuable for process purposes.

Steam Power.—The quantity of steam used in a process depends upon the thermal requirements, plus that to meet the mechanical power needs, if such power is generated at the plant (see Table 31). Steam-power-plant prime movers are well standardized and include: (1) simple engines using saturated steam, (2) simple engines using superheated steam, (3) compound engines, (4) triple- and quadruple-expansion engines, (5) impulse turbines and (6) reaction turbines. Other prime movers include water wheels, hydraulic turbines and internal-combustion engines (gas, gasoline and oil). Water wheels and hydraulic turbines require operation by specialists trained in these lines.

The chemical engineer may come into contact with such prime movers, but more often his plant equipment will be

TABLE 31.—COAL AND WATER CONSUMPTION AND BOILER CAPACITIES FOR VARIOUS TYPES AND SIZES OF STEAM ENGINES

Engine type	Size, horsepower	Water: Gallons per minute full load delivery	Water: Pounds per b.h.p.: Full load	Water: Pounds per b.h.p.: Half load	For delivered horsepower of rating: Boiler horsepower including auxiliaries	Coal—tons per 24 hr. at full load—125–150 lb. pressure 10,000 B.t.u. per lb. coal as used for following boiler efficiency (Horizontal tubular Scotch marine water tube): 40	50	60	70	80
Throttling	50	5	39	41	80	8.2	6.3			
Plain slide valve	100	9	36	39	145	15.1	11.7			
Noncondensing	150	12	34	37	205	21.4	16.5			
Automatic	100	7	29	30	115	13.3	10.4			
Plain slide or piston V.	200	12	27½	29	220	25.0	19.5	16.4		
Noncondensing	300	17½	26½	28	305	35.0	29.0	22.9		
Automatic	150	8½	23	28	140	15.7	12.2	10.4		
Tandem compound	300	15	22	26½	255	28.7	22.5	19.0	16.5	
Noncondensing	450	21½	21½	26	370		32.9	27.9	24.3	21.3
Corliss	200	10	22	25	175		15.6	13.1	11.4	
Simple	400	19	21½	24½	330		29.1	24.9	21.5	18.9
Noncondensing	600	27	21	24	485		42.5	36.3	31.5	27.6
Corliss	300	13	19½	26½	225			16.9	14.6	12.9
Compound	600	25	19	26	435			32.8	28.5	25.0
Noncondensing	900	37	18½	25½	610			46.0	40.0	35.0
Corliss	500	17	14½	16	280			20.9	18.3	15.9
Compound	1,000	31	13¾	15¼	505			38.0	33.0	29.0
Condensing	1,500	44	13¼	15	730			55.0	48.0	42.0

NOTE: Auxiliaries and steam losses are included in boiler horsepower and coal consumption on following basis: Up to 200 hp., 20 per cent; 300 to 600 hp., 15 per cent; 900 to 1,500 hp., 10 per cent.

Mechanical efficiency of all engines figured at 91 per cent.

electrically driven, with the electricity generated in the plant's own powerhouse, or purchased from a public utility.

Electrical Power.—Electrical power equipment necessary in a chemical plant is quite costly and is also somewhat expensive to maintain. This problem should be handled by a competent electrical engineer. However, it will be necessary for the chemical engineer to decide where power is required, where power

and lighting outlets are needed, and how much power or light is needed at each outlet. These requirements are sketched on a plan, and the electrical engineer will make the necessary calculations to determine the requirements for switches, transformers, panels, fittings, wire, conduits, fuse boxes, etc.

Electric Motors.—Motors may be classified according to (1) type, (2) speed and (3) mechanical features. The selection of motors depends upon the service demanded. An explanation of different motors should enable the chemical engineer to comprehend what the electrical engineer has available for use in the chemical plant.

1. Type.

a. Shunt-wound Motors.—Used where the work is of a fairly steady nature; where a considerable range of speed is desired; when fairly close speed regulation is required.

b. Compound-wound Motors.—Used when there are sudden calls of short duration for heavy loads; when heavy starting duty is required; when series motors could not be used on account of excessive light-load speeds.

c. Series Motors.—Used when excessive starting torques are required, but only when speed regulation is not important and only when light-load speeds do not exceed point of safety.

d. Squirrel-cage Motors.—Used when constant speed is desired and when normal starting duty is suitable.

e. Squirrel-cage High-resistance Motors.—Used when heavy starting duty is needed or when high slip is necessary to prevent excess motor overloads or intermittent peak-load demands.

f. Slip-ring Motors.—Used when heavy starting duty is required and speed control is necessary; maximum speed reduction practicable is 50 per cent; this is obtained by series resistor and speed is dependent on load.

2. Speed.

a. Multispeed Motors.—When direct current is not available; when three or four definite speeds, in conjunction with gear changes, will give desired speeds.

3. Mechanical Features.

a. Open.
b. Mechanically protected.
c. Semienclosed.
d. Totally enclosed.
e. Enclosed, externally ventilated.
f. Enclosed, self-ventilated.

g. Moistureproof.
h. Splash- and waterproof.
i. Submergible.
j. Acidproof.
k. Explosionproof.

Selection of motor for specific applications is facilitated by using Table. 32.

TABLE 32.—MOTOR APPLICATION

Speed classification	Power supply		N.E.M.A. class.	L.A. type	Type of motor	** Range of horsepower ratings	Starting torque per cent of full load	Maximum torque per cent of full load	Speed regulation per cent slip	General remarks	Agitators, mixers	Ball-rod-pug mills	Baling presses	Bending rolls	Blowers-positive pr.	Boring mills	Bucket elevators	Bulldozers
Constant speed	Alternating current	3 & 2 phase	A	S	Standard squirrel cage normal torque - normal starting current	½ to 300 H.P.	150	200 to 250	2 to 5	General purpose wide application simple control	◉				◉	◉		
Constant speed	Alternating current	3 & 2 phase	B	X	Squirrel cage normal torque - low starting current	7½ to 200 H.P.	125 to 150	200 to 225	2 to 5		◉				◉	◉		
Constant speed	Alternating current	3 & 2 phase	C	A	Squirrel cage high torque - low starting current	3 to 100 H.P.	200 to 250	175 to 225	4 to 5	Heavy starting simple control		◉					◉	
Constant speed	Alternating current	3 & 2 phase	D	K	Squirrel cage high torque - high slip	½ to 100 H.P.	200 to 300	200 to 300	8 to 15	Heavy starting - intermittent and fluctuating load		◉	◉	◉			◉	◉
Constant speed	Alternating current	3 & 2 phase	F	W	Squirrel cage low torque - low starting current	40 to 100 H.P.	50 to 80	125 to 150	4 to 5	Special purpose constant load light starting					◉			
Constant speed	Alternating current	3 & 2 phase	-	WX	Squirrel cage low torque	½ to 10 H.P.	100 to 125	175 to 200	4 to 5	Special service smooth reversal								
Constant speed	Alternating current	3 & 2 phase	-	H	Wound rotor	½ to 300 H.P.	200 to 250	200 to 250	*	Frequent & heavy starting.		◉		◉			◉	◉
Constant speed	Alternating current	Sing. phase	-	C	Capacitor - induction low torque	½ to 10 H.P.	50 to 75	175 to 200	4 to 6	Light starting direct conn. load								
Constant speed	Alternating current	Sing. phase	-	CN CU	Capacitor - induction normal torque	½ to 10 H.P.	150 to 200	175 to 200	4 to 6	General purpose infrequent starting	◉				◉			
Constant speed	Direct current		-	NA	Shunt wound	½ to 75 H.P.	150	†	5 to 10	General purpose steady loads	◉				◉	◉		
Constant speed	Direct current		-	NA	Compound wound	½ to 75 H.P.	175 to 200	†	10 to 25	Heavy starting fluctuating load		◉	◉				◉	◉
Constant speed	Direct current		-	NA	Series wound	½ to 75 H.P.	300 to 400	†	*	Heavy and frequent starting				◉				
Ajustable speed	A.C.	3 & 2 phase	-	M	Constant horsepower 2-3-4 speeds	¼ to 150 H.P.	125 to 150	175 to 200	4 to 6	Speed independent of load						◉		
Ajustable speed	A.C.	3 & 2 phase	-	M	Constant torque 2-3-4 speeds	¼ to 200 H.P.	125 to 150	175 to 200	4 to 6	Speed independent of load	◉	◉			◉		◉	
Ajustable speed	A.C.	3 & 2 phase	-	M	Variable torque 2-3-4 speeds	¼ to 200 H.P.	125 to 150	175 to 200	4 to 6	Speed independent of load								
Ajustable speed	Direct current		-	NW	Field control	¼ to 50 H.P.	150	†	5 to 10	Wide range flexible control						◉		
Ajustable speed	Direct current		-	NA	Variable voltage control	¼ to 30 H.P.	150	†	*	Extreme wide range flexible control								
Variable speed	A.C.		-	H	Wound rotor	½ to 300 H.P.	200 to 250	200 to 250	*	Limited range heavy starting	◉	◉		◉	◉		◉	◉
Variable speed	Direct current	Shunt	-	NA	Armature control	½ to 75 H.P.	150	†	*	Limited range dependent on load	◉				◉			
Variable speed	Direct current	Shunt	-	NA	Field and armature control	½ to 50 H.P.	150	†	*	Wide range limited application								
Variable speed	Direct current	Shunt	-	NA	Variable voltage control	¼ to 30 H.P.	150	†	*	Wide range low efficiency								
Variable speed	Direct current	Compound	-	NA	Armature control	½ to 75 H.P.	175 to 200	†	*	Limited range dependent on load		◉					◉	◉
Variable speed	Direct current	Compound	-	NA	Field and armature control	½ to 50 H.P.	175 to 200	†	*	Wide range limited application								
Variable speed	Direct current	Compound	-	NA	Variable voltage control	¼ to 30 H.P.	175 to 200	†	*	Wide range low efficiency								
Variable speed	Direct current	Ser.	-	NA	Armature control	½ to 75 H.P.	300 to 400	†	*	Limited range heavy starting				◉				

* DEPENDENT UPON LOAD AT NORMAL SPEED.
** HORSEPOWER RATINGS, TORQUE AND REGULATION DATA IS FOR 4 POLE (1800 R.P.M.) 60 CYCLE A.C. MOTORS
† MAXIMUM TORQUE IS LIMITED BY COMMUTATION. UNDER NORMAL CONDITIONS D.C. MOTOR DEVELOPS 200 TO

Application of Electric Motors.—There are two types of electric motor drive in general use in the modern industrial plant, *viz.*, (1) the direct-connected or individual drive, in which the motor is mounted on the machine or located near it, connected by chain, gear or belt; (2) group drive, in which one motor is arranged to drive a number of machines with widely fluctuating power

CHART FOR PROCESS INDUSTRIES

TYPICAL APPLICATION

CAPSTANS-CAR PULLERS	COMPRESSORS	CONVEYORS-LOADED START	CRANES-HOISTS-ELEVATORS	CRUSHERS-GRINDERS-WITH FLY-WHEEL	CRUSHERS-GRINDERS-NO FLY-WHEEL	DOUGH MIXERS	DRILLING MACHINES	DRYING TUMBLERS-CYL.	EXTRACTORS-LDRY. & CHEM.	FANS-CENTRIFUGAL	FANS-PROPELLER	GRINDERS-BUFFERS	HAMMER MILLS	IRONERS-FLATWORK	LATHES	LINE SHAFTS	MILLING MACHINES	MOTOR-GEN. A.C.-D.C.	MOTOR-GEN. D.C.-A.C.	MOULDERS-TENONERS	PLANERS-JOINTERS-SURFACERS	PRINTING PRESS-JOB	PRINTING PRESS-FLAT BED	PRINTING PRESS-ROTARY & OFFSET	PUMPS-CENTRIFUGAL-TURBINE	PUMPS-DISPLACEMENT	PUNCHES-SHEARS-HAMMERS	SANDERS	SAWS-CIRCULAR	SAWS-BAND	SHAPERS	STOKERS	VALVES	WASHERS-REV. MOTOR
					◉	◉	◉			◉	◉	◉		◉	◉	◉	◉	◉		◉	◉	◉			◉			◉	◉		◉	◉		
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AND 1750 R.P.M. D.C. MOTORS.
400% MAXIMUM TORQUE MOMENTARILY

requirements. The choice of type of drive depends upon the process and the arrangement of available equipment. The following arguments[1] are advanced for each type of drive.

A. Advantages of individual drive.
  1. Elimination of overhead shafting and belting.
    a. Line-shaft-friction losses eliminated.
    b. Maintenance of shafting and belting eliminated.
    c. Cleaner shop.
    d. Better light.
    e. Closer speed adjustment of the tool to the work.
  2. Location of machines to suit the continuity of a manufacturing process without regard to the location of line shafting.
  3. When only a few of the installed machines are to be operated (*e.g.*, overtime or slack season), it is not necessary to operate idle shafting and belting.
  4. On large work the tool may be taken to the work instead of the work to the tool.

B. Advantages of group drive.
  1. General advantages.
    a. Lower first cost.
    b. Lower electrical maintenance expense.
    c. Breakdowns with consequent delay to production less frequent.
    d. Possible to standardize more fully on motor styles and speeds, with consequent possibility of carrying complete line of spares, resulting in greatly decreased delay from such breakdowns as do occur.
  2. Particular advantages when using a.-c. power.
    a. Here the lower first cost extends back through the distribution system and to the powerhouse.
    b. If the power is purchased, this is reflected in a lower unit cost for power because of the greatly increased power factor attainable with group drive. Table 33 gives a comparison of individual and group drive costs on basis of motor and horsepower costs.

TABLE 33.—COMPARISON OF COSTS OF GROUP AND UNIT DRIVES
(Using squirrel-cage induction motors)
1,200 r.p.m.—550 volts

Horsepower of motion	½	1	10	40
Cost per horsepower	$68.00	$44.00	$12.90	$7.82
Number of motors	80	40	4	1
Total costs	$2,720.00	$1,760.00	$516.00	$313.00

[1] DRAKE, R. W., *Ind. Eng.*, February, 1929, p. 8.

Before any decision as to type of drive is reached, a careful study should be made to determine the most satisfactory and economical method in view of power requirements, location of machines and other important factors. Characteristics and limiting factors of mechanical power-transmission systems have been listed by Staniar and Perry[1] according to drive requirements of 15 transmission methods to aid in intelligent selection of systems to be used in specific cases.

Industrial Plant Wiring.—The rapid industrial development of recent years has been accompanied by the extensive application of electrical equipment in factories, mills and shops. This electrification of industrial plants has concerned itself principally with conversion from mechanical to motor drive, with the adoption of electric lighting and, more recently, with the use of electric furnaces, ovens, welding equipment and other special electric heating appliances. All these and other electrical applications call for suitable, dependable and safe wiring systems, and the installation of these systems has, therefore, made factory wiring a varied and difficult problem. The wiring must be safe and free from fire or accident hazards because of the large number of employees that may be at work in the plant. Only a very few of these know much about electricity and how to guard against shock or fire from its use. It is in order to avoid such hazards that the rules governing factory wiring in the national and local electrical codes have been made steadily more stringent.

Layout of Wiring Systems.—The principal wiring systems used in factory buildings are (1) open wiring, (2) molding wiring, (3) concealed knob and tube, (4) flexible conduit, (5) armored cable and (6) conduit wiring. In conduit wiring, the wires are run in metal ducts that are either exposed on the ceiling, walls or columns, or concealed in the walls and floors, or partly exposed and partly concealed. Conduit wiring is obviously more expensive but much safer and more reliable because the wires are completely protected from mechanical injury, from accumulations of dust, etc. Because of its superior safety, conduit wiring is insisted on for factory buildings in the larger cities.

Selection of the wiring system depends upon the nature of the building construction and the character of the manufacturing

[1] Staniar, W., and S. H. Perry, *Chem. Met. Eng.*, **41**, 626 (1934).

process carried out. In general, it may be said that the less expensive open wiring system may be used in any factory building where no special effort at fireproofing has been made, and in which no hazardous materials or processes are used. A further requirement is that the wires may be so arranged that they will not be readily disturbed. The Fire Underwriters' Laboratories and local ordinances should be consulted in all cases.

Circuits should be run as direct and as free from bends as possible. All wires for a circuit should be run in the same conduit, especially if alternating current is used. Distribution, junction, cutout and switch boxes or cabinets should be of ample size to accommodate additional feeders and branch circuits that it may be anticipated to add later, even if these are not to be installed for some time.

Separate feeders should always be installed for lighting and for power. The first reason for this is that starting and stopping of motors cause serious fluctuation of the circuit voltage. The second reason is that motor circuits are more often overloaded or short-circuited than lighting circuits and, therefore, more frequently interrupted by the blowing of fuses.

Motor Circuits.—Laying out the power circuits where there are many motors, and of different sizes, is often a difficult problem. Great care in laying out the power feeders and branch circuits is necessary because, not only would there be an investment waste in the use of an unnecessary length of heavy cable or wire, but also a needless power loss in overcoming resistance. Rules for finding the size of wire to run to any motor are quite well known, and many tables have been published, for both d.-c. and a.-c. motors. It is usual to allow not only for the efficiency of the motor, but also for at least 10 per cent over full-load current. The kind of service the motor is to render, the type of motor and its rating must be taken into account in determining the wire size.

Shafting.—Shafts are an important element in all power-transmission equipment, and much depends upon the proper selection of the shaft size. The American Society of Mechanical Engineers has made a careful and exhaustive study of the theory of stresses in shafts, and their findings confirm the results of good practice. The standard sizes, working stresses and design

factors have been incorporated in formulas and tables by Staniar,[1] offering a uniform and safe standard practice to users of shafting. Shafting, when properly aligned, can transmit power over distances of 6,000 ft. with an efficiency of 80 per cent.

Shaft Materials and Size.—Commercial shafting, as used generally for power transmission, is hot-rolled from mild steel bars and cold-finished or lathe-turned to finished size, up to about 6 in. in diameter. Corrosion is a vital hazard to shafting. Although any size shaft can be secured, it is advisable to use those sizes that are obtainable from stock without delay or extra charges, and for which the necessary couplings, collars and bearings are also stocked.

Stresses Found in Shafts.—Stresses commonly found in shafts are torsion or twisting only, flexure or bending only, or a combination of torsion and bending. To these might be added axial tension, or compression, due to endwise thrust as found in vertical shafts, in those driven by bevel or worm gears or in propeller shafts. Torsion is produced by turning moments of belts, ropes, gears, or in propeller shafts. Bending is produced by the combined pull of tight and slack sides of belts or ropes, the thrust of gears, chain pull, or the weight of parts supported or carried by the shaft. A shaft supported at two points some distance apart will have a bending stress resulting from the weight of the shaft. Any pulley, gear or sprocket placed on the shaft will increase the bending stress and, when force is applied to produce rotation, a torsion stress will be added to the bending stresses. The magnitude of these stresses and their location and direction of application in relation to the points of support, the character of the forces and the working strength of the shaft material are the prime factors in determining the size of shaft to use.

In heavy or important installations, the weight of shaft should be included approximately in the first calculation and checked when shaft size is determined. All stress factors acting upon the shaft should be considered, such as weight of shaft, belt, chain attachments, material carried, and unusual erecting and operating conditions. Shaft sizes are generally large when speeds are low, when bending loads are heavy or when bearings

[1] PERRY, J. H., "Chemical Engineers' Handbook," 2d ed., pp. 2510–2513, McGraw-Hill Book Company, Inc., New York, 1941.

are not close to the bending loads. Smaller shafts can often be used with safety and economy through increasing speeds and by proper mounting of the shaft in roller bearings. Shafts that are too small can often be relieved of excessive stress by adding another bearing or relocating bearings in relation to loads. A long clutch sleeve on a small shaft will develop trouble from the deflection of the shaft within the sleeve if the bearing is not sufficiently close to the sleeve. A liberal size in shafts and the installation of plenty of bearings are good insurance against loss in production and damage to life and property.

Information Required to Determine Shaft Size.—The following points must be determined in selecting shafting: (1) power requirements of each piece of equipment; (2) location of equipment and shafting; (3) kind of hangers, pulleys and bearings; (4) source of power for driven machines; (5) normal and maximum power to be transmitted; (6) characteristics of load, whether steady or fluctuating, gradually or suddenly applied, or shock loads (giving magnitude of variations and time of duration); (7) speed of shaft; (8) direction of rotation of driver and driven equipment; (9) center distance and relative elevation of driver and driven equipment.

Horsepower Requirements.—The horsepower requirements of each piece of equipment cannot be taken entirely as a criterion for the size of shafting, for, in addition, the type of equipment must be considered. Certain kinds of equipment, for example, operate more satisfactorily with unit drives. Again, the proper location of equipment as determined by the flow of materials is important in chemical plants. This consideration, more than any other item, controls the location of equipment and, consequently, the location of shafting for power transmission. Such location frequently so changes the distribution of power as to make it necessary to divide the shafting equipment into several line shafts and countershafts. Therefore, a careful consideration of plant design must precede any determination of individual line shafting that is based on horsepower distribution.

Bearings.—Almost any bearing, properly babbitted, lubricated and aligned, will transmit power with good efficiency. The common or plain bearing has an efficiency of 96 to 98 per cent, the roller bearing 98 per cent, and the ball bearing 99 per cent.

Four general types include the grease-lubricated, self-oiling, antifriction and oilless bearing.

The description of bearings by Staniar (Perry's "Chemical Engineers' Handbook," pp. 2508–2510) includes materials of construction and methods of installation. He states that the number of bearings and their location has a direct influence on the dead-load capacity of the shaft. Binding of the shafting in bearings usually does not occur where the deflection does not exceed 0.01 in. per foot. There is no definite rule of spacing, but on line shafting where the pulleys can be set close to the bearing, 8-ft. centers are good practice.

The factors governing selection of bearings are:

1. Diameter and speed of shaft.
2. Power and dead load.
3. Support.
4. Lubricant and lubrication methods.
5. Space limitations.
6. Operating conditions.
7. Initial and maintenance costs. Power losses per year caused by excessive friction loads have been determined (Perry's "Chemical Engineers' Handbook," p. 2510).

Hangers.—Hangers are, without question, one of the most important parts of line-shaft equipment, and upon their correct design, rigidity and bearing equipment depends in large measure the success of the entire distribution system. Ordinarily, sling hangers are suspended from beams or ceiling. These can be attached to the beams or rafters by various methods. The beam clamp is very satisfactory for attaching hangers because no drilling into the beam is required and because change of location, shifting or removal of shafting is facilitated by the use of such clamps. The sling hanger is used where shafting is subjected to extremely heavy bending or vibratory stresses. If supporting beams are more than 16 ft. apart, it becomes necessary to provide for additional supporting hangers and bearings at approximately 8-ft. distances, or to provide a much larger diameter shaft to give stiffness and reduce whipping. Another means is to employ a slow rate of shaft rotation.

Hangers with adjusting screws are much more satisfactory than rigid hangers or nonadjusting types, since perfect alignment of the shafting is essential. They are constructed on the

true ball-and-socket principle, permitting a free and effective movement of the bearing in the frame. They are easy to erect and line up, and their strength and rigidity ensure the permanent nature of the original alignment.

When the line shaft or countershaft is to be located near the wall or near a line of columns, then the bracket type of support is used. On these brackets can be placed any one of the types of pillow block, rigid, adjustable or split.

It is a common custom to use regular drop-hanger frames as floorstands by inverting them when the design calls for floor stands of low cost and compact proportions. Adjustable floor stands are made for use with pillow blocks. Both horizontal and vertical adjustments can be obtained by means of the wedge adjusting screws.

Couplings.—The length of shafting varies in standard sizes, but the choice of lengths is a local one, depending upon conditions in the plant and location of the hangers. These lengths of shafting are locked together by couplings of various designs. Types of coupling available include the flanged, ribbed and flexible (such as Ajax, Falk, Francke, leather link and floating center). Flanged couplings, when pressed and keyed onto the shaft and faced off, are practically part of the shaft. The use of these couplings ensures the permanence of the original alignment; this type of coupling is exclusively used on shafts over 6 in. in diameter. The ribbed coupling is adapted for general line-shaft service. Slight errors in aligning shafting are unavoidable; to compensate for such errors, flexible couplings are recommended.

The *Ajax* flexible coupling owes its flexibility and shock-absorbing quality to the use of rubber cushions which are ground to fit the flange sockets and cemented in place. The *Falk* coupling contains a spring grid fitting into specially formed slots in the hub, a construction which permits accommodation of angular and parallel misalignment, allows free end float, absorbs shocks and reduces oscillations. The *Francke* coupling owes its flexibility and shock-absorbing qualities to the use of flexible, laminated steel-pin units, which are locked in place by a single spring-retaining ring. In the *leather-link* type, the steel pins are connected by a special, oil-treated, endless leather belt. Such couplings are used for connecting motors to driven machines

and for low speeds and heavy loads. The *floating-center* coupling has a center disk with tongues finished for a sliding fit. Such couplings are suitable for transmitting heavy loads and can be used for reversing service. They are most frequently employed for connecting low-speed shafts where heavy torque is encountered.

Safety Collars.—In order to prevent shafting from moving sideways, safety collars are placed on each line of shafting in such places that shifting cannot occur in either direction. Also they must be located so that thermal expansion of the line shaft does not cause binding of the collar against the bearings. Safety collars are made both solid and split, for all standard sizes of shafting. They comply with all the legal requirements as to safety by having setscrews and bolts protected. An important use for safety collars is to carry the weight of slow-speed, vertical agitator shafts.

Friction Clutches.—Friction clutches used for power control are made in solid and split types, for any power capacity. They may be used as cutoff couplings or in connection with loose pulleys, sheaves, sprockets or gears. They save power by cutting out idle machines or groups of machines and permit motors and gas engines to attain a working speed before loads are applied. For the last purpose, automatic centrifugal clutches are often used. Friction clutches provide flexibility in power distribution in the connection and disconnection of reserve power units. Furthermore, they are safety factors for the instantaneous cutting off of power when necessary to safeguard workmen or machines. (See Perry's "Chemical Engineers' Handbook," pp. 2517–2518.)

Countershaft Units.—Countershafts are built to conform to standards and permit cutting off idle machines for the same reasons that mechanical clutches are used. They are built to meet any specifications with any type of hangers, bearings, pulleys, clutches, etc. Shifters are used to move the belts from power to idle positions. The loose pulley should not be placed on the main shaft.

Pulleys.—Pulleys are of three types: (1) single cast, which must be slipped over the end of the shaft and keyed on; (2) the split type; and (3) the clamp-hub type, which permits ready removal and change. Pulleys are flat or crowned, depending

upon requirements. Sizes are determined by the speed demands of the equipment and the shafting. Pulleys are made of cast iron, paper, plasticized fabric, wood and steel. If chemical fumes or liquids come into contact with pulleys, they can be protected by special resistant paints or nonoxidizing coatings.

According to Staniar it is essential to supply manufacturers with the following information when ordering pulleys:

1. Service.
   a. Single or double belt.
   b. Horsepower.
   c. R.p.m.
   d. Character of service.
2. Description.
   a. Solid, split, or clamp hub.
   b. Tight or loose.
   c. Flanged or special.
3. Diameter.
   Diameter in inches at the top of the crown.
4. Face.
   a. Crown or flat face.
   b. Width of face; check with width of belt according to type of belt and horsepower to be transmitted.
5. Bore.
   Exact diameter of shaft in inches.
6. Keyseat, or setscrewed.
7. Pulley dimensions should be given in the following order: (1) diameter. (2) face and (3) bore, such as 24 by 4 by $2\frac{1}{16}$ in.

Relative characteristics of various types of pulleys are also given by Staniar.

Belting.—Belt and cable driving of equipment is accomplished by leather, hair, stitched-canvas and rubberized-fabric belts and by rope and steel cable. For very dry places, oak-tanned leather belting is preferred, while rawhide or chrome-tanned leather or rubberized-fabric belt should be used for damp places. Oil and grease deteriorate rubberized belting. Canvas has the same strength as leather for belting but is more subject to shrink and stretch. Riveted or laced joints reduce the strength, while a properly cemented joint does not. Oak belting, when mineral tanned and waterproofed, is excellent for resisting deterioration from mineral oils, steam, moisture, acids, alkalies, etc., but is unsuited for high temperatures. Special coatings can be applied to belting to provide resistance against chemical gases and

liquids. Canvas belt treated with cellulose solution is serviceable when exposed to sulfuric acid fumes. Characteristics of each type of belting are given by Staniar together with methods of cementing, servicing and belt fastening; also formulas for power transmitted.

Belting Requirements.—It is necessary to determine the following values when studying belt requirements for a specific job.

1. Belt speed.
2. Horsepower.
3. Width of belting.
4. Arc of contact.
5. Effective pull when arc of contact is not 180 deg.
6. Size and speed of pulleys.

These can be determined by calculation[1] as follows:

1. To find the belt speed in feet per minute, multiply the diameter of the pulley in inches by 3.1416 and again by the number of r.p.m. of the pulley, and divide by 12 to get the result in feet per minute.

2. Using the diameter-revolution-velocity diagram of Fig. 37 for belt and pulley, a graphic solution is obtained by use of a straightedge, connecting diameter of pulley with r.p.m. and reading speed in the middle column. Likewise, either diameter of pulley or r.p.m. can be determined if any two values are known.

3. To find the horsepower of belting, for open drives without idlers and pulley diameters nearly equal, for single belts, multiply the belt speed in feet per minute by the width of the belt in inches and multiply that product by 55. Divide this product by 33,000. The quotient will be the horsepower that any good single belt will safely transmit. To find the horsepower of double and triple belts, multiply the result obtained for single belts by 1.5 for double, or by 2 for triple belts (see Table 34).

4. To find the width of belting, multiply the given horsepower by 33,000, and divide this product by the product of the belt speed in feet per minute, multiplied by 55 for single, 83 for double, or 110 for three-ply belt. The quotient will be the width of the belt required. (Alignment charts for belt horsepower are also in use.)

5. To find the arc of contact on the smaller pulley, for an open drive without idler pulleys, multiply the difference between the diameters of the pulleys in inches by 4.75, dividing the product by the distance between the pulley centers in feet, and subtracting the quotient from 180. The result is the arc of contact in degrees.

6. To find the effective pull where the arc of contact is not 180 deg., multiply the arc of contact, determined in accordance with (5), by 55, and

[1] "Belt Users' Book," p. 112, J. C. Rhoads & Sons, Chicago, Ill., 1929.

divide the product by 180. This is for single belts. Multiply by 1.5 for double belts. Multiply by 2 for triple belts.

Electrical Charge on Belting.—Electricity of high voltage can be generated on a moving power belt owing to (1) friction

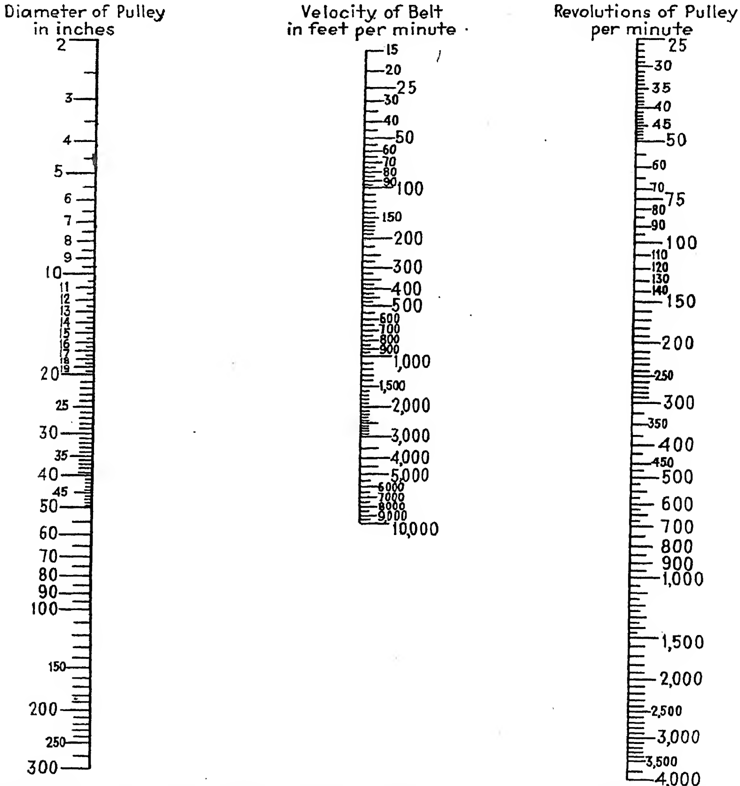

FIG. 37.—Diameter-revolution-velocity diagram for belt and pulley. (*J. C. Rhoads & Sons.*)

of the belt on the pulley, (2) separation of the belt from the pulley, or (3) friction of the atmosphere on the belt. The pulley can be grounded, but the belt, usually a nonconductor, allows the potential to build up under some circumstances until sparking

occurs. Even with the precautions taken in closed systems of industrial chemical equipment, flammable and explosive vapors are at times in evidence in areas surrounding, or adjacent to, such apparatus, causing fire and explosion hazards when belting is the power-transmission medium. The use of good metallic pulleys, copper wire stitched into belting and a suitable belt dressing, of which there are several kinds, is recommended for discharging belt static.

TABLE 34.—HORSEPOWER TRANSMITTED BY BELTS[1]
Pulley running at 100 r.p.m.

Diameter of pulley	Width of belts, inches																	
	2	3	4	5		6		8		10		12	14	16	18	20	22	24
	S	S	S	S	D	S	D	S	D	S	D	D	D	D	D	D	D	D
	4 ply	4 ply	4 ply	4 ply	6 ply	4 ply	6 ply	4 ply	6 ply	4 ply	6 ply	6 ply	8 ply	8 ply	8 ply	8 ply	8 ply	8 ply
6	0.29	0.43	0.57	0.71	1.3													
8	0.38	0.57	0.76	0.95	1.7	1.1	2.1											
10	0.48	0.71	0.95	1.2	2.2	1.4	2.6	4.2										
12	0.57	0.86	1.1	1.4	2.6	1.7	3.1											
14	0.67	1.0	1.3	1.7	3.1	2.0	3.7	2.9	5.9									
16	0.76	1.1	1.5	1.9	3.5	2.3	4.2	3.4	6.7	4.2	8.4							
18	0.86	1.3	1.7	2.1	3.9	2.6	4.7	3.8	7.5	4.7	9.4							
20	0.95	1.4	1.9	2.4	4.4	2.9	5.2	4.2	8.4	5.2	10.5	15.7						
22	1.0	1.6	2.1	2.6	4.8	3.1	5.8	4.6	9.2	5.8	11.5	17.3	20.2					
24	1.1	1.7	2.3	2.9	5.2	3.4	6.3	5.0	10.0	6.3	12.6	18.3	22.0	25.1				
30	1.4	2.1	2.9	3.6	6.5	4.3	7.9	6.3	12.6	7.9	15.7	23.6	27.5	31.4	35.3			
36	1.7	2.6	3.4	4.3	7.9	5.1	9.4	7.5	15.1	9.4	18.8	28.3	33.0	37.7	42.4	42.7	51.8	
40	....	....	3.8	4.8	8.7	5.7	10.5	8.4	16.8	10.5	20.9	31.4	36.6	41.9	47.1	52.4	57.6	62.8
48	....	....	4.6	5.7	10.5	6.9	12.6	10.1	20.1	12.6	25.1	37.7	44.0	50.3	56.6	62.9	62.1	75.4
54	....	....	....	6.4	11.8	7.7	14.1	11.3	22.6	14.1	28.3	42.4	49.5	56.6	63.6	70.7	77.8	84.8
60	....	....	....	7.1	13.1	8.6	14.7	12.6	24.1	15.7	31.0	47.1	55.0	62.8	70.7	78.6	86.4	94.3

[1] *Link Belt Co.*
NOTE: S and D (for single and double) in above table refer to thickness of leather belting: 4 ply, 6 ply, and 8 ply refer to thickness of cotton or rubber belting.

Rope Drive.—The two types of rope drive are: (1) the American or continuous-rope system, and (2) the English or multiple-rope system which consists of a series of ropes run side by side. The multirope system gives better assurance against a total breakdown, is flexible and easy to maintain, but requires more splices, does not provide for vertical transmission and presents difficulties in equalizing stresses between the ropes. Any quantity of power can be transmitted with rope drives, in any direction and over long distances. In the continuous-rope system, an automatic tension carriage maintains uniform tension

in the rope regardless of stretch, temperature, air humidity or variations in the load. Rope diameters are generally below $1\frac{3}{4}$ in. In general, sheave diameter should be at least 36 times the rope diameter. Most transmission ropes are wire, cotton, hemp or manilla. Cotton is most flexible but also weakest.

V-Belts and Sheaves.—The V-belt drive consists of a driving and a driven sheave, grooved for one or more belts of trapezoidal or similar cross section. The power is transmitted by the wedging contact between the continuous belts and the V-shaped grooves providing a transmission of 98 per cent of the power. This type of drive enables the motor to be placed close to the driven sheave, operating on unusually short centers with considerable space economy. Also, this type of drive provides for efficient and dependable transmission of power in speeds from 1:1 to 10:1, can be run with slack either on top or bottom, can be installed with the center line on the horizontal or the vertical, or inclined at any intermediate angle, with no slap, hum, or clicking. Cog type V-belts take care of the tension and compression phases in the circling of the belt. The belts cushion the shock of starting, accelerating, stopping or changing the load, and provide a steady and smooth flow of power, thus protecting the motor. The sheaves come in stationary- and variable-pitch grooves, the latter capable of making speed changes of from $33\frac{1}{3}$ to 100 per cent. Multiple-belt drives provide continuity of operation even if one or more belts fail for a short time until replacement of missing belt members can be conveniently made.

Chain Drives.—Chains may be used when a positive, high-efficiency drive is desired, and when the distances between the shaft centers are too short to use belts and too long for toothed gearing. The types in use are steel roller, malleable iron detachable and silent chain. These chains can also be made of stainless steel, Monel metal, nickel or bronze. The silent chain combines the best points of leather belts and cut gears, minus their disadvantages. All leather or rubber belt drives creep or slip, varying with atmospheric conditions, unbalanced loads or frequent pulsations. This is true whether flat or sheave type pulleys are used. Tightening the belt to reduce slippage brings unnecessary and extra strains on the bearings, increases frictional resistance and wastes power. The silent-chain drive is built up with projections which serve as teeth and mesh with metal spur

gears. (See Perry's "Chemical Engineers' Handbook," pp. 2519–2520.)

Gear Reduction Units.—Gear reduction units are commonly divided into three general groups and these are designated as spur, bevel and worm and worm wheel. A special form of the first is the herringbone.

The development of gear reduction units for power transmission has resulted in a wide choice of mechanisms now available. Gear units not only eliminate the dangers from static electricity incident to belting in the presence of flammable vapors, but also give the required accuracy of speed on certain types of apparatus. Owing to the complication of certain processes, the available space for transmission purposes is small and frequently the reduction ratio from power source to application is high. Or, speeds of rotation must be capable of instant change, with an accuracy down to fractions of a revolution. These are the exacting demands made on power-transmission mediums by the modern chemical manufacturing plant. It is obvious that belting, shafting, pulleys and ordinary open gearing can play only a small part in such transference of power. Trade catalogues of gear-reduction-unit manufacturers generally list ratios, horsepowers and speed capacities of their respective units.

According to Staniar (Perry's "Chemical Engineers' Handbook," pp. 2513–2515) ratios in single reductions up to 7:1 can be efficiently handled by belting, chains, or open gearing. In the spur-gear reduction unit, ratios from 1:1 to 500:1 are obtainable in one casing. The modern single worm-gear reduction unit should not be used for ratios over 70 or 80:1. Higher ratios up to 5,000 and 10,000:1 can be obtained by the use of the double worm-gear reducer, or by coupling two single reducers in tandem. The worm-gear reducer delivers its power at right angles to the power input. Since in many installations of chemical equipment this is not feasible, the spur-gear reduction unit, which reduces in a straight line, must be used.

Successful and satisfactory operation of gearing of all kinds depends upon proper alignment and rigid support to maintain the alignment, so that the teeth will properly mesh together and minimize vibration, which would cause chattering and excessive wear.

in the rope regardless of stretch, temperature, air humidity or variations in the load. Rope diameters are generally below $1\frac{3}{4}$ in. In general, sheave diameter should be at least 36 times the rope diameter. Most transmission ropes are wire, cotton, hemp or manilla. Cotton is most flexible but also weakest.

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Successful and satisfactory operation of gearing of all kinds depends upon proper alignment and rigid support to maintain the alignment, so that the teeth will properly mesh together and minimize vibration, which would cause chattering and excessive wear.

Variable-speed Mechanism.—Variable-speed motors, with the exception of those of special design, are not applicable for chemical installations where a considerable speed range is necessary. Therefore, manufacturers of power-transmission

TABLE 35

INFORMATION SHEET

Data for guidance in designing an American System Rope Drive for________

____

Date________________ Address____________________________

Answers to the following questions should be made as fully as possible. If space is too small in any case, use a separate piece of paper, designating the answer thereon by the proper question number. This information will be sufficient for all ordinary drives, especially if accompanied by a simple sketch on the back of this sheet. For more complicated situations we will send a competent representative to secure necessary data.

Fill out and mail to Dodge Manufacturing Co., Mishawaka, Ind.

1. What is the horse power required?	
2. What is the motive power; steam engine, gas engine, water wheel, lineshaft, etc.?	
3. If steam engine, what type and size?	
4. If gas engine, what cycle and how many cylinders?	
5. What is the speed of the driving shaft?	
6. What is the speed of the driven shaft?	
7. Are the shafts parallel?	
8. Are either or both shafts horizontal or vertical?	
9. If both horizontal, are they on the same level?	
10. If not on same level, which is the higher and how much?	
11. What is the distance on centers of driving and driven shafts?	
12. What is the largest diameter of wheel that can be placed on driving shaft?	
13. What is the largest diameter of wheel that can be placed on driven shaft?	
14. May the ropes run direct between driving and driven sheaves, or must they run over, under or around obstructions? Give directions and distances.	
15. Must the rope turn any angles? If so, describe them, stating degrees, distances, etc.	
16. Will the rope be exposed to the weather or entirely under cover?	
17. Where may the tightener and tracks be placed most conveniently?	
18. What are the directions of motion for driving and driven shafts?	

machinery have developed what are called *mechanical speed transformers*, of which the Reeves type is an example. This machine consists essentially of two parallel shafts mounted in a rigid frame, each of which carries a pair of cone-shaped disks with their apexes facing inwardly so as to form together a spool-shaped pulley. An endless belt, wedge shaped in cross section, passes around the two spool-shaped pulleys formed by the two pairs of disks. The effective diameter of these pulleys is dependent upon the separation of the component disks. This is controlled at will by the operator, one pair increasing in separation by an amount equal to the decrease of the second pair upon adjustment. Such a drive may be operated equally well when mounted upon the floor, ceiling, or vertically against the wall or against the frame of the driven machine.

Data Required.—An information sheet typical of the sort of detailed information necessary in designing or ordering a mechanical power-transmission system is given in Table 35.

CHAPTER VIII

DEVELOPMENT OF THE DESIGN PROJECT

A thorough study of the development of a chemical engineering plant project, from the conception of the idea through to the successful establishment of a chemical manufactory, involves more than is within the scope of this book. The essential plan of designing a chemical plant does not include the detailed study of markets, and hence such a study will only be dealt with briefly to show the position of such studies among the technical factors in project development and plant design.

A clear and concise statement of the project with all specifications for the plant process, all laboratory data, and any other pertinent chemical or engineering facts must be presented to the chemical engineer designer before he begins his study of the project. Together with the process data supplied by the research and the development laboratories, and the semicommercial plant, the designer must consider how to coordinate the economic and technical factors. Definite principles should be followed.

Feasibility.—Perry, in Table 36, presents an outline of preliminary feasibility study which contains the sequence of items that must be taken into consideration before a new chemical product can be successfully developed and marketed. He states that a seasoned chemical engineer of broad experience and sound business judgment can do more to promote the economic development of new products than perhaps anyone else in the organization of the company.

TABLE 36.—OUTLINE OF PRELIMINARY FEASIBILITY STUDY[1]

I. Consider all possible reactions.
   (*a*) List by classes or types and/or individual reaction, the reasons for or against the utility of each reaction or class of reaction.
II. Recommend reaction or groups of reactions selected for laboratory investigations—with reasons therefor.
III. Economic factors for preliminary consideration.
   (*a*) Raw materials.
   Availability;

[1] PERRY, J. H., *Chem. Met. Eng.*, **43**, 75 (1936).

TABLE 36.—OUTLINE OF PRELIMINARY FEASIBILITY STUDY.[1]—(*Continued*)

Quality: presence or absence of deleterious or valuable impurities and their effect on use as crude materials;
Quantity: present and future supply;
Freight rates: to consuming points;

(*b*) Thermodynamics of reaction or reactions with:
Summary of pertinent physical and chemical properties of reactants and products;
Equilibrium involved;
Yields probable;
Optimum conditions for optimum yields;
Cost of raw materials per pound of product at probable yields.

(*c*) Suitable materials of construction of probable utility.

(*d*) Markets: uses of products (and by-products)—
Present and possible;
Extent of present markets with statistics.

(*e*) Estimates of the present and possible costs of production of principal competitors.

(*f*) Probable percentage of present United States production and of imports that are possible for proposed process or product.

(*g*) Detailed estimate of production cost of proposed product by selected reaction or reactions.

(*h*) Sales and sales service—customer research.
Is cost of introduction likely to be excessive?

(*i*) Shipping restrictions and containers.

(*j*) Effect of storage upon product.

(*k*) Safety and fire hazards of raw materials, production processes, by-products and products.

(*l*) Estimate of investment for plant and auxiliaries.

(*m*) Probable profits.
Margin of profit per pound of product;
Total profit probable under optimum and probable conditions;
Probable return on the investment;
Does it warrant further consideration and immediate experimental research and/or development? If immediate further development is not desirable, when and what change of present conditions are necessary or desirable before further development is attractive?

(*n*) If immediate development is desirable:
Outline questions to be answered, and facts to be secured by further research and developments.
Indicate the crucial data and information that are lacking.

(*o*) Plant location.

IV. Final report to management with copies for research, production and sales executives.

[1] PERRY, J. H., *Chem. Met. Eng.*, **43**, 75 (1936).

It is of considerable importance to a careful survey to stress the factors that will play an important role, not only in the design itself but also in the construction and operation of the chemical plant. Plant design not only must be technically satisfactory but must also be economically satisfactory; the goal of the design is to secure a workable plant with the maximum return on the necessary investment. Any plant design must also consider the safety factors not only for the sake of its workmen but also for the public at large, the equipment, the plant and the product. The general wheel outline as presented in Fig. 38 brings out an interrelation of the various factors. Each individual design of a chemical plant is usually a highly specialized case, and a detailed generalization scheme cannot be outlined that will be in its entirety a thorough coverage of the requirements of all chemical plant design problems.

I. TECHNICAL FACTORS

Markets.—Market surveys are generally made by the trade or market survey department or division of the company, or they can be obtained from special trade survey consultants or organizations that have been established in various parts of the country to provide complete reports on any commodity, its uses, forms, quality, quantities, availability to location, import and export data, tariffs, trade agreements, consumer testing consumption, production and distribution. This applies not only to finished products but likewise to raw materials and by-products.

Flow Diagrams.—To the design engineer a flow sheet of equipment and materials in process is considered the first clarifying step. This is a transposition of the research and development laboratory notes and reports into the terminology of the engineer. The flow diagrams present a picture of materials flow, process operation flow, process equipment flow, materials handling, storage, future plant expansion and labor, water, power, and fuel requirements. From this picturization the departments, the possible sequence and number of units required and the distribution of labor are evident. The materials balance and an energy balance are worked out, and the quantitative interrelationships are then presented on the flow sheets.

Equipment.—Performance and service are demanded from all equipment. Much valuable information for the selection of

equipment is available from manufacturers of equipment. Much of the equipment for materials handling and for unit operations and processes is standardized, and, whenever such equipment serves the purpose, it is selected in preference to special designs, thus substantially lowering the cost, providing for ready duplication of equipment, and availability of repair parts. One

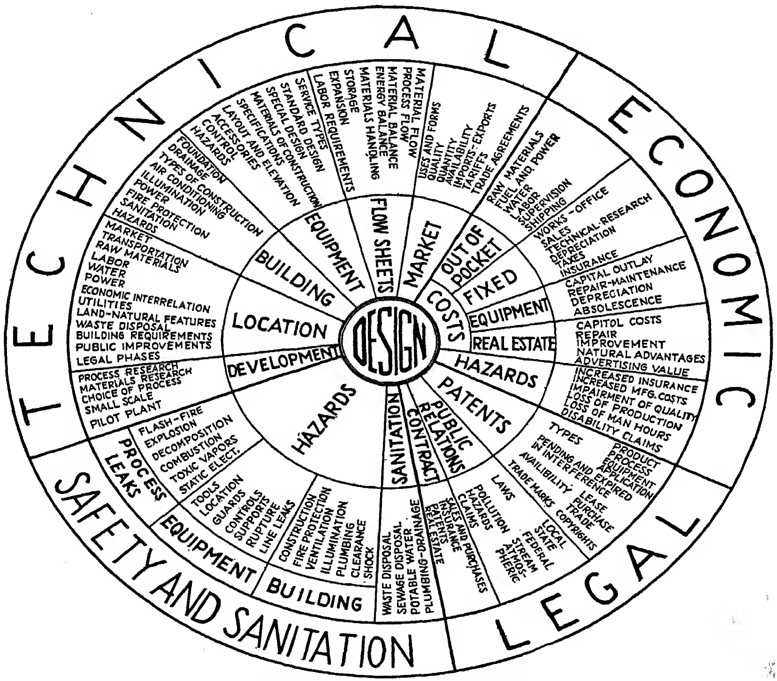

FIG. 38.—Plant design factors.

should not hesitate to meet any problem that requires a special design and the use of special materials even if it is considered that a new design is an experiment for the manufacturer and the user. The changes in demands and services for commodities sooner or later lead into pioneer fields of equipment design. Manufacturers hesitate to use a new material on a standard design, since either a change in process equipment to meet a

satisfactory compromise with the manufacturer, or an exhaustive pilot-plant study must be undertaken.

Plant Layout.—Plant layout or economic arrangement of equipment follows selection of type of equipment. Arrangements of equipment even for the same process are varied and generally are an expression of some architectural inclinations of the designer, not always resulting in as economical and practical organization as would be possible if layouts and arrangements of similar or allied plants as published in current literature were studied and improvements made upon such layouts, if changes are deemed necessary. Accessories and control devices are essential to effective operation of equipment and flow of process. The operation of a proposed piece of equipment or process is studied carefully. Frequently the proper arrangement of equipment effects a material saving in labor.

Buildings.—The chemical processing and the materials handled govern the general design requirements of buildings. Careful attention is given to the arrangement and layout of the equipment, and then a building is considered as surrounding all this assembly or only such portions as require housing. In chemical buildings, special attention is given to foundations for building and equipment, sanitation and plumbing, the type of floor, structural frame, walls, roof, fume handling, explosion possibilities, lighting, ventilation, drainage, heating, air conditioning, fire protection, and power-plant orientation. The types of buildings and the service requirements for each can be supplied by the industrial building manufacturers. The building serves as a protective cloak to be used as shelter for equipment or operators.

Location.—In general, the following items are considered vital in plant location: Proximity to market, raw materials, transportation, labor supply, water supply, power supply, economic interrelation with other industries, and specific plant requirements. There are other plant and process location matters that are of real importance to, and exist as real responsibilities of, the chemical plant design engineer of commercial plants for the manufacture of chemicals and chemical formulations, such as land, local ordinances, public improvements, utilities, waste disposal and climatic condition. All the factors that enter into the

problem of plant or industry location also affect the choice of local sites, and must be considered by the design engineer.

Development.—One of the clearest expositions of chemical engineering development is one given by Whiting[1] who divides the evolution of the process into five definite stages:

1. Laboratory stage.
2. Small-sized model.
3. Large-sized or development unit.
4. Semicommercial plant.
5. Commercial plant.

Whiting's observations may be summarized as follows:

The first step in testing the correctness of the underlying technical principles is to conduct such experiments as may be necessary for a full preliminary study of the technical side of the problem in hand. It is not the function of the laboratory to produce accurately the condition of practical work, but rather to enable the experimenter to test out the fundamental principles on a small scale with a correspondingly small outlay of time and money. The aim should be, therefore, to isolate the idea, to divorce it from any conditions which may be misleading in their effect and, also, to subject it to a severe test to determine its stability.

The novelty of the process must be investigated by a thorough study of the state of the art in textbooks, periodicals, patent office records, etc., an undertaking which requires time and patience and not a little self-control. And just as important as the search covering the novelty of the process is a study to determine whether the basic commercial conditions surrounding it are sound, that is, whether the raw materials required are to be obtained at a reasonable price and in sufficient quantities, whether the operation is likely to involve any overly hazardous conditions, and whether there is a permanent market of sufficient size and stability for the product. From a practical standpoint, it is useless to spend time and money on a process not commercially sound, but this is being done constantly by inventors all over the world.

Development passes to the small-scale or small-sized model when the laboratory yields satisfactory results. In order to facilitate the study of each operation variable, the design of the small model plant should be simple and flexible to meet the

[1] Whiting, J., Eighth International Congress of Applied Chemistry, **21,** 203 (1912).

great variety of conditions that should be investigated to determine optimum operating conditions. The small plant, moreover, should be large enough to permit the manufacture of sufficient quantity of the product to enable the experimenter to determine its quality, to permit the use of commercial materials, and to ascertain the effects of impurities on the success of the process. With increase in size, the optimum operating conditions as determined for the small plant may not hold true. Consequently, flexibility in design is still a desirable thing in a large size or development plant. According to Whiting, this is the most critical stage in the whole program of development. At this stage of development a broad knowledge of engineering materials and fundamentals, and of other aspects of design, is of greatest assistance. In order to obtain engineering data essential for the pilot-plant investigation of the commodity selected, the following considerations may be important.[1]

1. Procedure essentials.
2. Raw material characteristics.
3. Chemical flow sheet.
4. Corrosion characteristics.
5. Effect of impurities.
6. Heat considerations.
7. Unit operations required.
8. Material handling.
9. Storage.
10. Engineering flow sheet.

The Pilot Plant.—The pilot plant serves as the second valuable adjunct for the chemical engineer, and all data must be available to him. In addition, the pilot plant must at all times answer and solve problems of application of materials of construction, incidental speeds of reaction, time, temperature, heat transfer and other items that escape initial observation in the laboratory. The laboratory and the pilot plant together must serve as potential sources of information, even if analytical, control, research and development work have been finished on the problem. Whiting states that "at the beginning of this stage it is necessary to consider a new and very necessary element of success—money.

[1] VILBRANDT, F. C., *Ind. Eng. Chem.*, **31**, 253 (1939).

The first three stages consume large amounts of time and energy, but little hard cash."

The pilot-plant space should be large enough to permit manufacture of a sufficient quantity of product to enable the experimenter to determine its quality, to permit the use of commercial materials and to ascertain the effects of impurities on the success of the process. Flexibility in design is desirable. The layout for this stage should consist of units large enough to give information on variations in the proportions and conditions of operations, without consuming large quantities of material.[1]

The pilot-plant stage should determine such factors as: cost of operation, proper methods of transportation around the plant, the optimum balance between production capabilities of the various pieces of equipment, flow relations, industrial hazards, possibilities of creating a public nuisance, reclamation of valuable by-products, and the disposal of large tonnages of waste. The pilot plant must solve problems concerning materials of construction, incidental speeds of reaction, time, temperature, heat transfer and other items that have escaped previous observations. Its product is salable, and the unit can serve as the source of supply for consumer testing. Even after the commercial plant is erected, the pilot plant should remain available for some time for the study of possible changes in the process, without costly interference with production in the commercial unit.

A mathematic approach to the conversion of pilot-plant data to full-scale production has been proposed by Edgeworth-Johnstone[2] and Damkohler[3] on the principle of similarity.

The Commercial Plant.—If the process can survive the exacting tests of semicommercial operation, and estimates indicate that the production cost will be sufficiently low, the last and final stage of development—the full-sized commercial plant—may be carried out with the assurance that all the risks, both technical and economic, have been minimized. The size of the plant will depend upon the requirements set forth in the original demands for the design of the plant.

This final step is the coordination of all chemical and engineering data obtained and their translation into a definite organized

[1] VILBRANDT, F. C., *Chem. Met. Eng.*, **42**, 554 (1935).

[2] *Trans. Inst. Chem. Engrs. (London)*, **17**, 129 (1939).

[3] *Zeit. Elektrochem.*, **42**, 846 (1936).

unit. Access must be had to trade literature for selection of types and specific pieces of equipment. Capacities and performance are studied. Preliminary layouts are attempted, and the best flowing arrangement obtained. Organization of the equipment by means of template gives a picture of the possibilities of different layouts. After arriving at the most desirable layout, actual drawing of the plan and elevation of the assembly is undertaken followed by preconstruction costing. In order to design a commercial unit, including housing for the production of the specified commodity, the following considerations are important:[1]

1. Specifications of equipment.
2. Specifications of materials.
3. Selection of commercial equipment.
4. Plan.
5. Elevation.
6. Location of plant.
7. Operating instruction for labor.
8. Selection of personnel.
9. Preconstruction costing.
10. Production costs per unit of material.

Cooperation in Development.—At this point in plant design it is essential in most cases to obtain suggestions and criticisms from the pertinent personnel of various departments for a consultative review of all facts and data to be used in plant design. It is also essential to have available the services of the control laboratory or some of its personnel designated for specific duty for the process design in connection with the testing of the products and materials.

The research chemists who have been carried along with a process and those who have been in charge of the semiworks and pilot plant and the semicommercial plant will be used in a principal supervisory role in such final designs. Furthermore, their detailed experience with the process in question necessitates that they be held responsible for many or most of the decisions regarding the final plant design. The experience and judgment of all company employees who have had specific experience with any of the unit processes, unit operations, auxiliaries, or special equipment used or proposed for use in the proposed plant and processes must be utilized to the fullest possible extent. An

[1] Vilbrandt, F. C., *Ind. Eng. Chem.*, **31**, 253 (1939).

excellent guide and check list showing the steps in the development and introduction of new products in process industries through production and marketing has been prepared by the editorial staff of *Chemical & Metallurgical Engineering*.[1]

II. ECONOMIC CONSIDERATIONS

Costs.—A compilation of all data relative to cost of raw materials, land, buildings, labor and supervision, equipment, legal fees, taxes, insurance, interest, etc., should be obtained by the designer on a preconstruction cost accounting basis as a forerunner to actual operation cost accounting if the project proves financially feasible. The purpose and result of preconstruction cost accounting for the design engineer is to permit the making of a report, showing what possibilities exists for profits and earnings under proper management, even before the investment is made. Cost data can only be current and must be modified as price conditions vary, but in competent hands, current cost data are useful and serves their purpose—that of indicating possible profit, or stopping further expenditure if the venture labels itself as uneconomic.

Many correlations are available for graphically indicating the interrelationships of such items as sales costs, materials cost, and fixed costs. The limits of profitable and unprofitable operations are thereby identified. Items for consideration in full costs are classified as (*a*) costs for raw materials, fuel, power, water, labor, supervision, packaging and shipping; (*b*) fixed charges for works and main office overhead, sales costs, technical research, depreciation, taxes and insurance; (*c*) equipment costs; and (*d*) real estate costs (see Chap. XI).

Costs in Safety.—The hazards present are a direct function of fire insurance rates that can be obtained. A decrease of the hazards may effect important savings in the insurance items of the overhead costs. In this connection, it has been known that the cost of a complete automatic sprinkler system has been entirely defrayed by the resulting decrease in fire insurance rates. Such protective schemes and equipment are not so easily paid for, but they frequently can be justified on economic grounds alone. Hazards also involve loss of production and men's service as well

[1] *Chem. Met. Eng.*, **43**, 2 (1936).

as impairment of product quality; reduction of hazards thus becomes an economic problem.

III. SAFETY CONSIDERATIONS

It is important that engineers continue to recognize safety and fire hazards of the processes they are operating. From every standpoint, these hazards are a liability, and their actual and potential costs must be emphasized in process thoughts and plans. The chemical industries today, through their medical, safety and fire protection departments, have intensively investigated hazards of all kinds, and much information and data thereon are available. There is, then, every incentive and a real necessity for including a survey of safety and fire hazards in a study of chemical and chemical engineering processes or individual pieces of equipment.

Building and Process Equipment.—Rational plant design is concerned with safety factors[1] and with the need for minimizing such building and equipment hazards as corrosion, fire and explosion, and personal hazards from fume and poison. Process leaks and spillage hazards are quite common in chemical plants, and measures should be considered in design to minimize such hazards. Equipment hazards, hazards due to bad lighting for operation of equipment, reduction of corrosion through selection of proper materials or by providing proper guards come under the jurisdiction of safe practices (see Table 37). The relation of equipment hazards to personal hazards is self-evident, and proper design considers not only process flow, but the course of action of the operators and other personnel in a plant. Also, it must be concerned with the disposal of wastes as affecting persons outside the jurisdiction of the plants. The effect of zoning ordinances and other legal restrictions to operations cannot be minimized; no matter how highly satisfactory a process and a design of a plant for operating such process may be from the technical and economic viewpoint, the safety and disposal measures if not properly attended to may effectively trip up the entire design.

Labor Relations in Safety.—Most public and private enterprises are cognizant of their moral and ethical responsibilities toward those who have placed their health, welfare and livelihood

[1] KEEFER, W. D., *Chem. Met. Eng.*, **46**, 334 (1939).

TABLE 37.—MAJOR SAFETY AND FIRE HAZARDS

Process Location:

Hazards of corrosion, health, explosives and fire to adjacent life and property.

Buildings:

A. *Arrangement and height* for economies of space and production and, simultaneously, maximum safety and fire protection.
B. *Type of construction* and fire walls, barricades, etc.
C. *Clearances*—railroads, overhead and side clearances; widths of doors, walkways, windows, etc.
D. *Water supplies*—primary and secondary, fire mains, hydrants and hoses.
E. *Contiguous electrical hazards*—high-tension lines, substations, etc.
F. *Ventilation.*
G. *Illumination.*

Processes:

A. *Leaks and spillages*—gas or liquid leaks, foams, sprays and mists.
B. *Toxic Vapors*—possible hostile legislation.
C. *Closed systems, or efficient ventilation.*
D. *Combustion*—spontaneous and flammable materials.
 1. Raw materials.
 2. Intermediate materials.
 3. By-products.
 4. Finished products.
E. *Flash and fire points and ignition temperatures.*
F. *Explosions and detonations*—vapors, dusts, etc.
G. *Rupture of vessels.*
H. *Decomposition of materials.*
I. *Static electricity.*

Equipment:

Types—Location; guarding; controls; tools; first aid.

in their hands. Safety and fire hazards are potential deterrents to the maintenance or attainment of optimum technical efficiencies and of desirable quantity of product. If any hazards are known and if proper safeguards or protection are not provided, the psychology of the operator will frequently be such that his attention will be drawn thereto and, to that extent, withdrawn from his immediate duties. As his attention is taken from his real job and duties, his efficiency and therefore the efficiency of his operation will decrease, resulting in the improper discharge of his duties and, through improper washing, filtration, drying, heating or any other of the more or less essential operations of a chemical process, may result in an unsatisfactory product.

A study of the cause of injuries in 50,000 major and minor industrial injury cases reveals that 30 per cent are due to faulty instruction, 22 per cent to inattention, 14 per cent to unsafe practice and 12 per cent to poor discipline, whereas 12 per cent are due to inability, physical and mental unfitness of the employee, and only 10 per cent to mechanical hazards.

If the man or men, who have been specially trained for a particular job or jobs, are temporarily or permanently removed from the operation as a result of ill health, accidents, or fires, the operation of such a process suffers. Therefore, the costs of an operation or process may be increased appreciably in a large number of ways, particularly as regards the items mentioned above, *viz.*, loss of production, impairment of product quality, insurance costs, disability claims, loss of service of trained men and the costs of training other men.

Sanitation.—Sanitation in the plant as affecting conditions outside the plant is a process problem, and care must be taken in considering (1) the potable water supply and its protection from contamination by the plant or outside sources, (2) the personal plumbing, (3) the drainage, and (4) waste and sewage disposal.

IV. LEGAL PHASES

Patents.—The patent situation pertinent to any product, process, equipment, use or application of any commodity should be considered by the legal department concurrent with the design. The commodity or processing for the commodity may be so involved in patents that one could not proceed with the actual production and distribution. Not only existing patents, but patents in interference and under adjudication, and patents pending must likewise be considered by the legal department. Patents available by purchase and lease and by participation in patent pools are considered as safeguards for carrying out a plant design. Trade-marks and copyrights are likewise property that must be recognized and properly protected through legal agreements carried out by the legal department.

Infringement.—A search in the Patent Office is made during which every feature (even the apparently unimportant details are frequently of real importance) of each logical division or

step of the process is studied. In this search, both the expired and the unexpired art must be included, the expired art to indicate what can be done legitimately and the unexpired art to indicate the limitations or restrictions on what can be done legitimately. If unexpired patents are found which would be infringed by the desired process, then a study of their validity and scope must be made with reference to the expired patents. As regards infringement, it should be emphasized that no unexpired patent can cover the material disclosed in an expired patent except by the well-known legal procedure of combining items, that were previously known, to make a new contribution of knowledge. If a single expired patent can be found that covers the process desired for use, there is no reason why the process cannot be legitimately and safely used, at least from the patent standpoint. The determination of the scope and the validity of a patent with respect to its infringement is a question of law, and, as such, it should be undertaken by someone who is conversant with such matters and, preferably, one who is an experienced patent attorney before any definite action is taken. But, the patent attorney should not be relied upon for the technical information involved; the technical aspects belong in the sphere of the technical man. If the proposed process is new, it is desirable that it be protected by patent or patents as completely as possible from a monopolistic standpoint. Such patent protection is essential.

Public Relations.—The legal department should acquaint itself with all local, state and Federal laws that pertain to the manufacture of the commodity, its transportation and application, atmospheric[1] and stream pollution through the disposal of wastes, and the possibility of claims for injury, death, or disabilities in connection with the production and use of the commodity to be manufactured. The design engineer should be made acquainted with all such legal entanglements, so that he may advise the legal department and be properly advised in connection with pertinent details of design to ameliorate probable hazardous conditions and unsafe practices.

Contracts.—The design engineer leaves all contracts to the legal department, but, for purposes of acquainting himself

[1] VILBRANDT, F. C., and J. R. WITHROW, *Trans. Am. Inst. Chem. Engrs.*, **13**, ii, 43 (1921).

with limitations that may later arise in the fulfillment of his design project, he should recognize the detailed contractual relations that must be promulgated for actual commodity production.

DESIGN OPERATION ORGANIZATION

Check Diagram.—The check diagram (Fig. 39) should be used to ensure complete consideration of all items for a departmental sequence. Each of the responsible executives of an organization is concerned with the problems in his particular sphere of activity. Individual plants have departments or divisions additional to those indicated in Fig. 39, whereas others use combinations or other terms. To ensure progress and a vigorous and healthy prosecution of the project, an executive conference of the various chiefs in each of the above groups is called at frequent intervals. When the executive conference decides that the investigations warrant a step forward toward commercial plant realization, the project is then turned over to the engineering department for detail design.

Conference Board.—The conference board undertakes an extensive and careful planning of the plant, generally divided into the following: equipment, layout and elevation, service demands, building, operation, and personnel. The equipment studies are delegated to the engineering research personnel, the service demands to the plant engineering department, the building to the construction division—as also the layout and elevation—which the operating department should be called on for experienced advice for handling the personnel and the production.

The information that should be available at this stage is as follows:

1. Complete lists of all the plant and equipment required, so far as is known at this stage.

2. A site layout showing the sidings, roads, buildings, points of entry of water supply, electric and gas supplies (if any), effluent and sewage outfalls, and the general run of underground piping, including drains.

3. Particulars of the dimensions of the various buildings, length, breadth, number of floors, height to eaves, and floor loadings; decisions regarding the type or types of buildings to

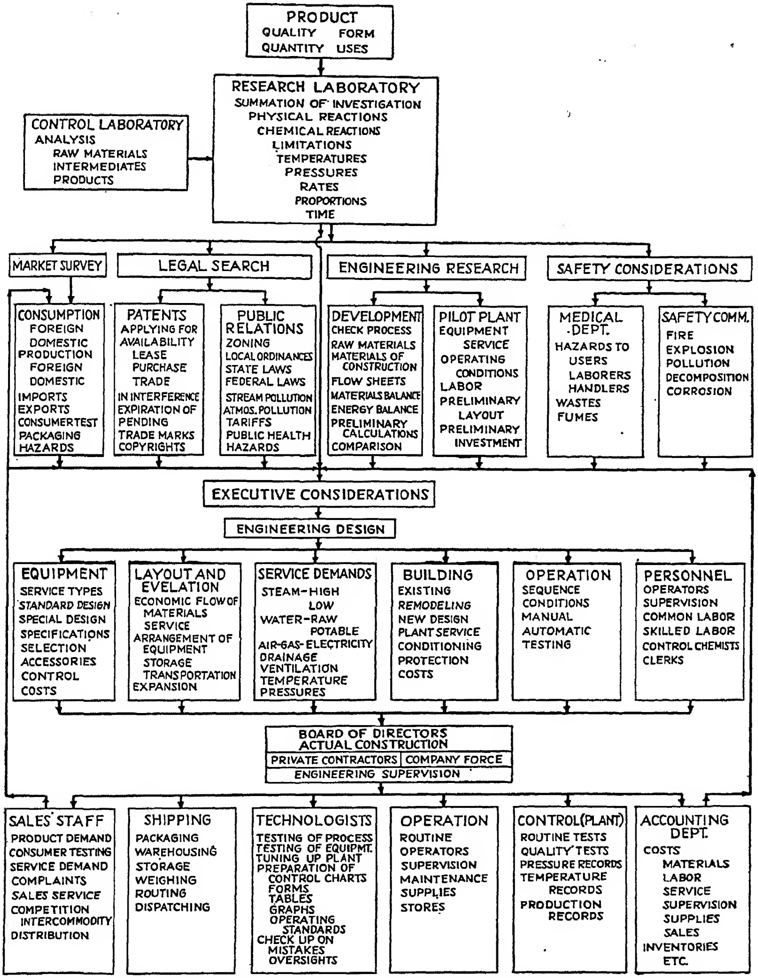

FIG. 39.—Organization check plan. (*Courtesy of Department of Chemical Engineering, Virginia Polytechnic Institute.*)

be used, *i.e.*, whether steel encased in brickwork, steel framed with brick panels, ferroconcrete, etc.

4. Particulars of the services required and their distribution to the various buildings, *e.g.*, quantities of steam per hour at various pressures, electric power, feed and cooling water, etc. This information should be supplemented by charts or curves showing the load factor and times of peak load throughout the day and week for all services both in summer and winter.

Construction.—Now, the whole job may be placed in the hands of a firm of consulting engineers and architects, who will prepare all drawings and specifications, place all contracts, and be responsible for the proper carrying out of the work at all stages; or the company places all contracts both for buildings and plant direct; its own technical staff prepares all drawings (apart, of course, from contractors' drawings) and specifications and supervises all work on the site, thus making the company responsible for the correct carrying out of the work. This arrangement has the advantage that no consultants' fees are payable and that the directors of the company are in a much better position to control expenditure and make sure that subcontracts are placed on the most advantageous terms. There is also considerable saving in time, provided, of course, that an adequate and efficient staff is available to cope with the work expeditiously. There are, of course, various intermediate arrangements between these two extreme methods. For instance, an architect may be employed to look after the building work only, while the company takes on the plant and equipment; or a firm of consultants may be called in to handle the power plant, or the construction of a deep-water wharf, or some other specialized part of the work. The help of specialists who are not consultants can often be used effectively. For instance, some of the reinforced concrete specialists will undertake the design of reinforced concrete foundations and provide working drawings, provided the reinforcing steel is obtained from them, and the big steel structural firms will always be prepared to design steel framed buildings to any given requirements.

Operation.—After construction the first step consists in the servicing of the plant by means of the operating and technological departments. A cooperative effort to tune up the plant,

test all equipment and the process, and prepare for the routine of operation and control shortens the trying period of breaking in the process. Some modifications and changes may become apparent, and the decision to alter or proceed again should be decided by conference. After routine production sets in, the sales, shipping, accounting and other executive functions proceed.

SOURCES OF INFORMATION

Textbooks.—Data can be secured through the use of published information. In order properly to arrive at correct quantitative data, the chemical engineer must have a thorough knowledge of the principles of chemical engineering. To utilize the fundamental equations for purposes of calculation is essential; reference to any one or all of the textbooks on principles and elements of chemical engineering is the first prerequisite of a chemical engineer. "Principles of Chemical Engineering," by Walker, Lewis, McAdams and Gilliland,[1] "Elements of Chemical Engineering by Badger and McCabe,[2] "Applications of Chemical Engineering," by McCormack[3] and "Handbook of Chemical Engineering" by Liddell[4] are standard reference textbooks.

Handbooks.—Chemical engineering handbooks, such as Perry's "Chemical Engineers' Handbook,"[5] are the next references for information of a general nature that might be applicable to the process in hand. In addition, many manufacturers of chemical equipment supply information in tables which enable the engineer readily to find data he may need. Unfortunately there are insufficient data of this sort available completely to cover the field of chemical engineering on all problems, so again recourse must be made to the basic principle formulas. Some computations of data in tables can be found in the chemistry, physics, chemical engineering, architectural, civil and mechanical engineering handbooks. Any such aids are not only desirable but essential.

[1] 3d ed., McGraw-Hill Book Company, Inc., New York, 1937.

[2] 2d ed., McGraw-Hill Book Company, Inc., New York, 1939.

[3] 1st ed., D. Van Nostrand Co., Inc., New York, 1940.

[4] 1st ed., McGraw-Hill Book Company, Inc., New York, 1922.

[5] PERRY, JOHN H., editor, 2d ed., McGraw-Hill Book Company, Inc., New York, 1941.

Intimate knowledge of the contents of the various handbooks comes only with frequent contact; the chemical engineer should avail himself at all times of the opportunity to consult and use the standard handbooks. Such handbooks as Marks' "Mechanical Engineers' Handbook,"[1] Kidder-Parker's "Architects and Builders' Handbook,"[2] "Handbook of Chemistry and Physics,"[3] "Handbook of Chemistry,"[4] "Handbook of Engineering Fundamentals,"[5] and Olsen's "Chemical Annual,"[6] belong to this list. One or more of these tools are found in every chemical engineer's library.

The "Chemical Engineering Catalog."—The *Chemical Engineering Catalog*[7] serves as the best reference book on manufacturers of chemical engineering equipment and products. This catalogue often includes sufficient information in the material presented by the subscribing advertisers to answer the equipment-selection problem.

The *Chemical Engineering Catalog* is published annually. At the present time (1941–42) it includes five indexes, *viz.:* (1) alphabetical index of firms represented; (2) trade-name index; (3) equipment and supplies index; (4) chemicals and raw materials index; and (5) technical and scientific book index. Unfortunately the *Chemical Engineering Catalog* is incomplete inasmuch as not all manufacturers of chemical engineering equipment, supplies, chemicals and raw materials advertise in it. Nor does it contain the voluminous quantity of data, direct and relative, that is contained in the mass of literature sent directly by manufacturing companies. To include all this information would make the catalogue cumbersome; therefore, the selection of material to be included depends upon the judgment of the advertising companies and of the advisory committee that aids in editing the catalogue.

[1] Marks, L. S., editor, 4th ed., McGraw-Hill Book Company, Inc., New York, 1941.

[2] Kidder, F. E., and H. Parker, 18th ed., John Wiley & Sons, Inc., New York, 1931.

[3] Hodgman, C. D., 25th ed., Chemical Rubber Publishing Company, Cleveland, 1941.

[4] Lange, N. A., Handbook Publishing Co., Sandusky, Ohio, 1941.

[5] Eshbach, O. W., 1st ed., John Wiley & Sons, Inc., New York, 1936.

[6] Olsen, J. C., editor, 7th ed., D. Van Nostrand Company, New York, 1934.

[7] The Chemical Catalog Company, Inc., New York; published annually.

Trade Literature.[1]—There is a great profusion of trade literature consisting of pamphlets, circulars, bulletins and catalogues, containing information such as advertising claims, applications, specifications and other pertinent information on all types of chemical engineering equipment and materials. That the data and information contained in these pamphlets, circulars and bulletins are quite valuable will be attested to by anyone who has had occasion to design a plant, a piece of equipment or a process; or who has wished to purchase a new or replace an old piece of equipment, or to obtain information on chemical products. Many of these pieces of literature are comprehensive treatises on the theory and application of the equipment which their issuers have for sale. To the chemical engineer, the performance data and dimensional drawings contained in some of these pamphlets are of inestimable aid in the ready solution of his design and process problems. This follows in part from the fact that he depends upon and uses standard-designed equipment whenever a satisfactory product is available, resorting to specially designed parts and units only when a standard design does not fit his need.

Chemical Engineering Publications.—It should be pointed out that the rapid advances in our chemical industry have placed it in a situation where the designer must keep up with the very latest data which may in any way become useful to him, not only in the present problem but also in any likely future work in his line. In particular, chemical engineering periodicals, and other publications devoted to his branch of engineering, are in a position to bring him the latest practical results of experimental designs in other lines. *Transactions of the American Institute of Chemical Engineers* and the magazines *Chemical & Metallurgical Engineering*, *Chemical Industries*, and *Industrial and Engineering Chemistry* are at present the outstanding American sources of information on progress in the chemical engineering field.

General Periodicals and Publications.[2]—In lieu of the strictly chemical engineering books a number of sources of general information are called upon not only to perform their own rightful functions but also to compensate for the lack of information not found elsewhere. These most useful divisions of sources of

[1] VILBRANDT, F. C., *J. Chem. Educ.*, **10,** 354 (1933).
[2] FIELD, CROSBY, *Chem. Met. Eng.*, **38,** 190 (1931).

information include: (1) publications of chemical and chemical engineering societies; (2) bulletins of manufacturers of chemicals; (3) bulletins of the manufacturers of special materials and metals; (4) publications of university laboratories; (5) pamphlets from industrial and trade associations and industrial institutes; (6) government publications from various bureaus such as Chemistry and Agricultural Economics in the Department of Agriculture, Census, Mines, Patents and Standards in the Department of Commerce, Internal Revenue in the Treasury Department and the U. S. Tariff Commission.

Plant Visits and Expositions.—Another group of information services that should be assiduously cultivated for general information, but only rarely renders available specific data to aid in solving a particular problem, includes visits to process plants, expositions and other demonstrations. It is indeed rare that opportunity affords visits to plants making the same products, but there are elements of similarity in most plants that are of considerable value. The exposition is of value principally in the opportunity it affords to study the latest developments in equipment, products and materials.

Equipment Manufacturers' Laboratories.—A service that can be of great value and yet is frequently the most dangerous is the equipment manufacturer's demonstration laboratory. The danger lies principally in the attempt to use it instead of the pilot plant. It would be much safer if the miniature equipment could be transported from the manufacturer's laboratory to the private plant, used and returned.

Personal Experience.—The last information service to be specifically mentioned is the engineer's personal experience. It should be applied last, but it is most important. Attempts have been made to publish certain standardized specifications for mechanical equipment, but so far this has not been done in a general fashion for a large number of types of chemical equipment; so it is still the fundamental job of the engineer to make his own check list. This should contain details of the specifications, and in particular should have underscored the obvious details most frequently omitted.

All these tools must be used with keen judgment. It is rare indeed that an engineer makes an error of commission, i.e., rare for him to make a mistake in a detail of design that he should not

have made in the light of his experience. The most frequent errors are those of omission, where some vital factor not previously met in the engineer's experience steps in and invalidates a design that would otherwise have proved meritorious. Experience, especially the broadening kind in fields other than the particular one containing the problem on which the engineer is at the moment working, is a shield against such dangers.

Suggested Collateral Reading

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CHAPTER IX

FLOW DIAGRAMS

Supplied with the proper information, a statement of the problem, and access to chemical-laboratory and pilot-plant data (see Chap. VIII), the chemical engineer next devotes his attention to the development of flow diagrams. For the preliminary stage there are three of these showing: (1) the flow of materials or chemicals through the process; (2) the sequence of chemical engineering unit operations involved; and (3) the equipment to be used in the process. In the case of the last, specific equipment is not always indicated, especially where a choice of several types accomplishing the same unit operation is available. As an indication of the principal sorts of equipment used in 80 of the most important unit operations, Table 38 is presented. It will be observed that there is often considerable latitude of choice, but this will usually be narrowed by the circumstances of the individual problem.

These three diagrams are called qualitative flow diagrams and after careful development of each, the three are correlated into one; this will show the kinds of raw materials entering the process, the sequence of manufacturing processes and the equipment to accomplish these operations, as well as the paths by which intermediate and finished products emerge from the process.

The flow of materials in process will indicate the departments needed and possibly the approximate sequence and number of units. It must be borne in mind that preliminary findings will be subject to some necessary modifications as details develop and as handling and manufacturing arrangements are determined more definitely. Only through such flexibility will it be possible to obviate impracticable building considerations or to fit the process into an existing structure.

Occasionally the chemical nature of the material processed is such as to require special attention. In such cases it is desir-

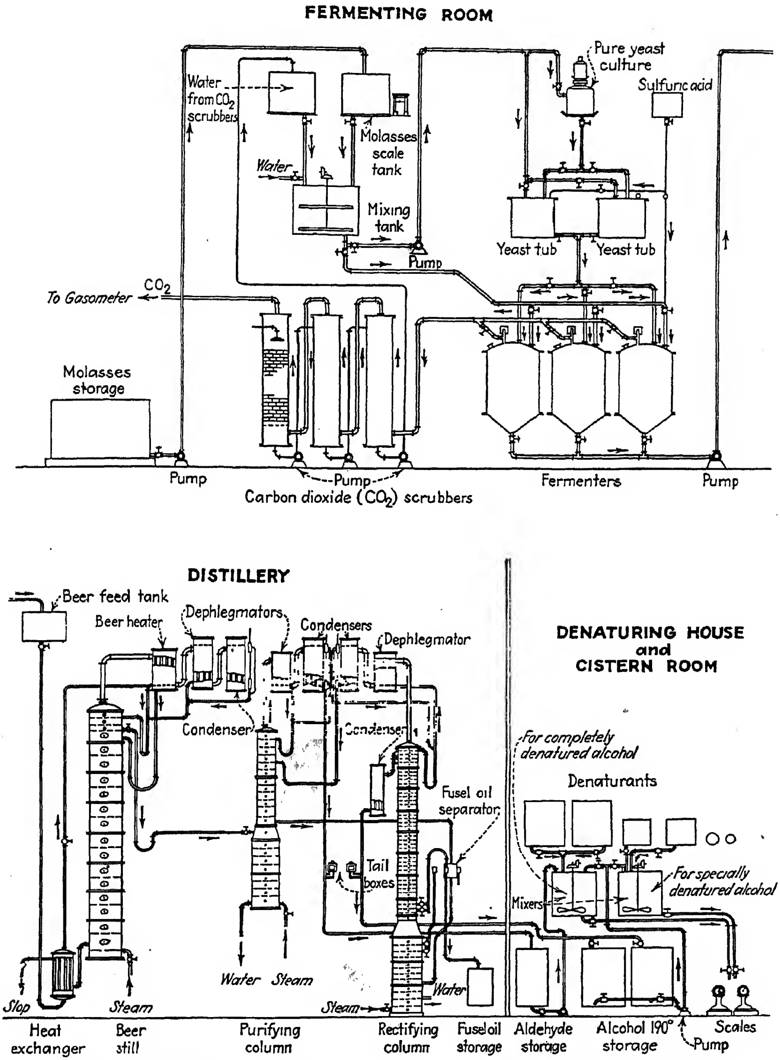

FIG. 40.—Qualitative flow diagram of a modern molasses distillery. (*G. T. Reich, Chem. & Met. Eng.*, **41**, 64, 1934.)

TABLE 38.—CLASSIFICATION OF UNIT OPERATIONS AND EQUIPMENT[1]

Classification of Unit Operations	Equipment
MATERIALS HANDLING.	
Gathering	Cranes, drag lines, industrial cars, pneumatic conveyors, car dumpers, power and hand trucks, stackers, skids.
Storing	Bins, hoppers, sheds, barrels, drums, open storage, skids, stackers.
Transporting	Automobile trucks, industrial cars, Dry-Flo cars, barrels, drums, kegs, power and hand trucks, skids, box and gondola cars.
Conveying	Belts, screws, elevators, bucket and pallet conveyors, Redlers, solids pumps, pneumatic, flight and vibrating conveyors.
FLUIDS HANDLING.	
Gravity flowing	Piping, flumes, conduits, valves, fittings.
Pressure pumping	Plunger, piston and rotary pumps, pulsometers, blow cases, air lifts, screw pumps, piston compressors, pipe lines.
Kinetic pumping	Centrifugal and turbine pumps and compressors, fans, blowers, jets, pipe lines.
DISINTEGRATION.	
Crushing	Jaw crushers, gyratories, disk crushers, Hadsel mills, rolls.
Grinding	Ball and hammer mills, rolls, ring-roll mills, cage mills, chasers.
Pulverizing	Hammer, ball and tube mills, stamps, colloid mills, ring-roll and ball-and-race mills, rod mills, roller, attrition and buhrstone mills.
Shredding	Hammer and attrition mills, grindstones.
Chipping	Hogs, chippers.
Masticating	Masticators.
Spraying	Spray nozzles, turbine-type dispersers, pumps, piping, valves, spray chambers.
MIXING.	
Mixing	Chasers, flight and screw mixers, tumbling barrels, buhrstone mills, roller mills, ball mills, turbine, paddle and propeller mixers, coating pans, pumps.
Agitating	Turbine, propeller and paddle mixers, air-lift and air-bubble agitators, pumps, compressors.
Kneading	Rolls, double-arm mixers, chasers, epicyclic chasers (Lancaster).
Emulsifying	Turbine, paddle and propeller mixers, colloid mills, homogenizers, pumps.
Dispersing	Turbine, paddle and propeller mixers, colloid mills, homogenizers, pumps.
Diffusing	Tanks, vats, diffusion cells.

HEAT TRANSFER.

Heating.

Direct heating............ Electric arc, resistance and induction furnaces, fuel-fired furnaces, kilns, muffles, etc. (heating by radiation and furnace gases).

Indirect heating.......... Heat exchangers, furnaces, etc., used to supply heating medium such as hot air, water or oil, or vapors such as steam, mercury, diphenyl, diphenyloxide, etc.

Cooling.

Air cooling............... Heat exchangers, condensers, cement coolers, recuperators, preheaters.

Water cooling............ Condensers, internal-combustion engines, refrigerating equipment, process coolers, waste-heat boilers.

Ice cooling............... Process vessels.

Spray cooling............. Spray ponds, cooling towers.

Refrigerating............. Steam jet units, centrifugal vapor units, compression and absorption units.

SEPARATION.

Physical.

Crystallizing[2]............. Ponds, vats, agitators, agitated troughs, rotary and rocking crystallizers, salting evaporators, vacuum crystallizers, grainers.

Condensing[2].............. Jet and surface condensers, spray chambers, heat exchangers, fractional condensers, fractionating columns.

Melting[2].................. Furnaces, kettles, crucibles, reaction equipment.

Freezing[2]................. Molds, solid CO_2 presses, refrigeration equipment.

Adsorbing................ Char and contact filters, false bottom and agitated tanks, packed towers, activated carbon, silica gel and other adsorbents.

Physical (*Solution*)

Leaching................. Tanks, vats, Pachuca and Shanks tanks, classifiers, ball, tube and stamp mills.

Dissolving[2]............... Tanks, vats, agitators.

Extracting............... Tanks, vats, classifiers, diffusion cells, agitators, gas equipment.

Percolating............... Percolators (solvent circulated).

Washing................. Tanks, agitators, classifiers, thickeners, filters, centrifugals.

Gas absorbing[2]........... Packed towers, spray chambers, bubble and plate towers, Woulff bottles, tourills, blowers, exhausters.

Physical (*Vaporization*).

Distilling................ Pot and pipe stills, packed, bubble and plate columns, condensers, separators.

Evaporating[2]............. Tanks and kettles, atmospheric and vacuum evaporators (single and multiple effect), film and forced-circulation evaporators, water stills.

Drying.................. Atmospheric and vacuum dryers, tunnel, truck, pan and tray dryers, conveyor dryers, rotary, drum and festoon dryers.

Subliming[2]................ Retorts, condensing chambers.

TABLE 38.—CLASSIFICATION OF UNIT OPERATIONS AND EQUIPMENT.[1]—(Continued)

Classification of Unit Operations	Equipment
SEPARATION (*Cont.*).	
Electrical.	
Magnetic separating	Magnets (permanent and electro), magnetic pulleys and chutes, high-intensity separators.
Electrostatic separating	Huff separator, Cottrell precipitator.
Electrophoresis	Clay extruding machinery (only present known commercial application).
Mechanical.	
Screening	Grizzlies, trommels, gyrating, shaking and vibrating screens.
Sieving and bolting	Sieves, sifters, bolters (rotary, shaking, vibrating), turbine sifters.
Pressing[2]	Hydraulic and mechanical presses, curb presses, expellers, continuous filter presses (Thompson).
Draining	Draining decks, screens, classifiers, tables, dewaterers, filters, centrifugal filters, nutsches.
Dialyzing	Animal membranes, vegetable parchment, cellulose film; used as bags or as diaphragms.
Gas diffusing[2]	Porous plates, unavoidable diffusion of certain gases through metals at high temperatures.
Impinging	Air and gas washers, entrainment separators, spray chambers, air and gas filters (wetted or oiled surface), P & A tar extractor.
Mechanical (*Filtration*).	
Gravity filtering	Slow sand filters, false-bottom tanks, Hardinge clarifier, Laughlin thickener, nutsches.
Pressure filtering	Rapid sand filters, clarifiers, filter presses, leaf filters, edge filters, continuous filter presses (Thompson).
Vacuum filtering	Rapid sand filters, disk filters, leaf filters, drum-type filters, Dorrco filter, Genter filter, filter-type thickeners, savealls, nutsches.
Centrifugal filtering	Continuous, semi-continuous and batch centrifugals with perforated baskets.
Mechanical (*Differential Settling*).	
Flotation	Air- and mechanically-agitated flotation cells, skimmers.
Classifying	Reciprocating and spiral rake classifiers, bowl and drum classifiers, hydraulic cones, multiple-spigot classifiers.
Chamber (basin) settling	Settling basins, dust chambers (void, chain-filled, shelved), Spitzkastens.
Air separating	Equipment employing change of air direction, velocity, or both, *i.e.*, cyclones, Multiclones, vacuum, fan and dynamic-type separators.
Jigging	Hydraulic jigs.
Tabling	Concentrating tables.
Vanner separating	Vanners.

Mechanical (*Settling and Decanting*).

Sedimenting	Settling basins, tanks, vats, thickeners.
Liquids settling	Settling tanks with multiple or swing draw-off pipes.
Centrifugal settling	Continuous, semi-continuous (Rotojector), and batch centrifugals and centrifuges with solid baskets, cyclones.

CONTROL.

Sampling	Automatic samplers, manual samplers, "thieves," "Samplitt."
Indicating	Thermometers, flowmeters, electrical instruments, gravity and density meters, scales, etc.
Recording	Thermometers, flowmeters, electrical instruments, gravity and density meters, scales, etc.
Integrating	Flowmeters, wattmeters, scales.
Analyzing	Manual analysis, Orsats, automatic Orsats, thermal conductivity analyzers, pH and conductivity analyzers, calorimeters.
Manual controlling	Valves, dampers, switches, gates, scales.
Automatic controlling	Temperature controllers, flow controllers, automatic feeders, density controllers, pH and conductivity controllers, etc.
Proportioning	Proportioning pumps, dry and liquid feeders, weight controllers.

MISCELLANEOUS PHYSICAL OPERATIONS.

Catalyzing	Catalyst chambers, converters, catalyst carriers, catalysts including metals, oxides, acids and salts.
Flocculating	Settling basins, chemical feeding equipment, Dorrco Flocculator.
Deflocculating	Agitators, tanks, vats.
Compressing	Compressors, molding presses, preform presses, high-pressure apparatus, coolers, heat exchangers, pumps.
Expanding	Expansion valves and chambers, specialized equipment such as that used in Masonite process, heat exchangers, vacuum pumps, condensers.
Coagulating	Reaction equipment, tanks, vats.

[1] After Olive, T. R., A New Classification of Unit Operations, *Chem. Met. Eng.*, **41**, 230 (1934).

[2] These operations generally but not necessarily used for separation.

able to divide the flow diagram into several parts and thus to separate from the more advanced and less changeable section that portion which is apt to require frequent modification. The chemical engineer should develop the technique of orienting subservient details around those operations, pieces of equipment or chemical reactions which cannot be modified. In other words, it is essential to determine the more rigid details and then develop the flow diagram around these less adaptable items. Figures 40 and 41 are picturizations of complete qualitative flow diagrams. Here the procedure of operation and equipment sequence is presented as a whole, for study and for subsequent guidance toward the quantitative flow diagram. Qualitative flow diagrams or flow sheets can be found for a large number of the chemical process industries in industrial chemistry texts; an excellent compilation of 120 condensed flow sheets, with data on raw materials and service requirements, has been published by *Chemical & Metallurgical Engineering*. Reference should also be made to a monthly series of pictorial flow sheets beginning with the January 1939, issue of the same magazine.

Quantitative Flow Diagrams.—With a complete equipment flow diagram available, the next consideration must be given to size of equipment, quantities of materials in the process and other service requirements. Calculations are made concerning storage containers for raw material, intermediate and finished products. All heat-transfer needs in individual pieces of equipment are determined. Consideration is given to the flow of liquids, gases or solids in pipes, flumes, ducts, drains and equipment. Demand is calculated for water, steam, gas and air, and for electricity for power, light, ventilation, fume elimination and materials handling equipment.

The next step in the organization of data in rational plant design is to include in the equipment flow diagram all quantitative data acquired. This will enable the chemical engineer to have clearly before him the coordinating units in the flow of materials through the process, *i.e.*, the quantitative data in connection with each step (see Fig. 42). A checkup of the quantitative flow diagram will indicate in what parts of the process information is still lacking. With a complete flow diagram of this sort, the chemical engineer is ready to proceed to the next

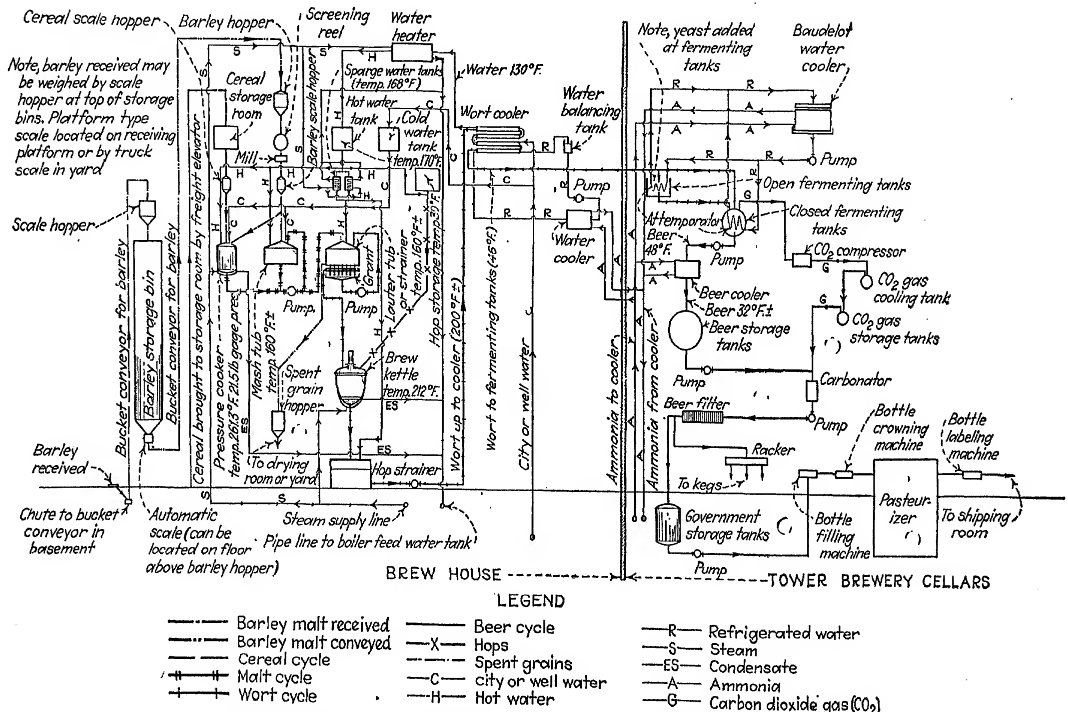

FIG. 41.—Qualitative flow diagram. (*Victor Buhr, Food Industries*, **5**, 123, 1933.)

This flow diagram represents a modern brewery cycle, using equipment for a capacity of 100,000 bbl. per year. By the judicious use of pumps it has been possible to reduce the building height one or two stories below that customarily employed.

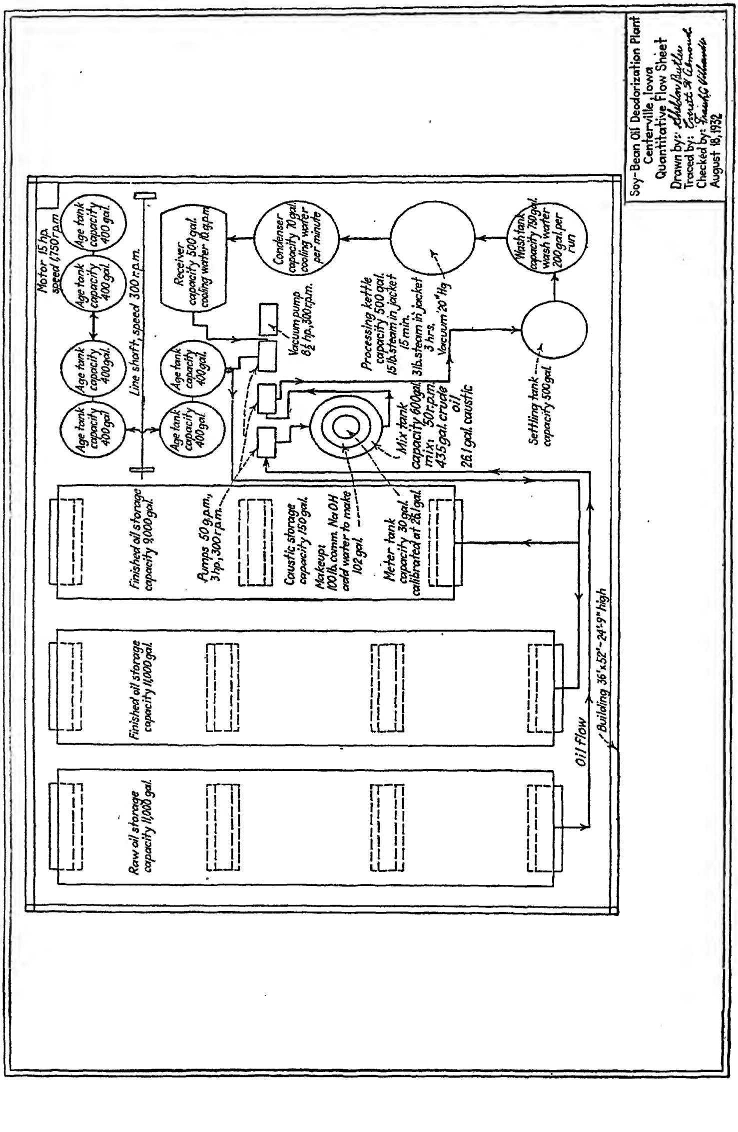

FIG. 42.—Pictorial quantitative flow sheet for soybean-oil deodorizing plant.

step in design—selection of standard equipment from trade literature.

Project Data on Materials.—In order to show how data are used in the solution of a design project, the following section on the design of a ferrous sulfate plant gives detailed calculations used in determining the requirements of individual pieces of unit operations equipment.

Project A—Ferrous Sulfate Recovery Plant

Design a plant for the recovery of ferrous sulfate contained in the waste pickling liquors resulting from the pickling of steel in a galvanizing plant. There is available 85,500 lb. per day of waste liquor. The recovered product is to be in the form of ferrous sulfate heptahydrate crystals.

A. Laboratory and Semiworks Data.

Composition of the waste pickling liquor:
- $FeSO_4$, per cent 25
- H_2SO_4, per cent 2
- Free from sludge.

Gravities of solutions at critical points:
- Waste pickling liquor, at 175°F 1.216
- Neutralized liquor, at 136.5°F 1.222
- Evaporated liquor, at 169°F 1.360
- Mother liquor from centrifuges, at 75°F 1.255
- Sludge from filter press, at 136.5°F 1.750

Temperatures at critical points:
- Pickling solution available at .... 175°F.
- Liquor from second evaporator .... 169°F.
- Liquor from crystallizer .... 75°F.
- Mother liquor from centrifuges .... 75°F.
- Cooling water .... 68°F.
- Room temperature .... 60°F.

Solubility and other data:
- $FeSO_4.7H_2O$, at 75°F .... 73.8 g. per 100 g. water
- at 169°F .... 198.5 g. per 100 g. water
- Crystal yield, cooling from 169°F. to 75°F. . 124.7 g. per 100 g. water
- Crystals from centrifuge carry 5 per cent water
- Crystals from drier are essentially dry heptahydrate
- Yield of heptahydrate considered to be 100 per cent.
- Analysis of scrap iron: silicon .... 0.6 per cent
- carbon .... 0.5 per cent
- Retention time for neutralization .... 48 hr.
- Heat of formation of $FeSO_4$ in solution, per lb.-mol.... 8,110 B.t.u.
- Heat of crystallization of $FeSO_4.7H_2O$, per lb.-mol..... 167,760 B.t.u.

Weight of $FeSO_4.7H_2O$, dry crystals	66 lb. per cu. ft.
wet, centrifuged	72 lb. per cu. ft.

Steam conditions:

At 15 lb. gage, 249.7°F., latent heat of vaporization	945.3 B.t.u.
At 2 lb. gage, 218.4°F., latent heat of vaporization	966.2 B.t.u.
At 18 in. vacuum, 169°F., latent heat of vaporization	996 B.t.u.

Heat-transfer coefficients:

Film coefficient, inside tubes, 6 ft. per sec	805.4
outside tubes, 1 ft. per sec	126
Coefficient for cast iron	36
for copper	238
Over-all coefficient, open tank, natural convection	25
evaporator	300
forced convection, inside pipes	200

Specific heat of solutions, assume 1.0.

B. Reaction Calculations (Basis: 24-hr. Operation).

Waste pickling liquor:

$FeSO_4$ = 25 per cent = 85,500 × 0.25 = 21,375 lb.
H_2SO_4 = 2 per cent = 85,500 × 0.02 = 1,710 lb.
Water = 73 per cent = 85,500 × 0.73 = 62,415 lb.
Total = 85,500 lb.

Neutralized pickling liquor:

$$Fe + H_2SO_4 = FeSO_4 + H_2$$
$$55.84 + 98.08 = 151.90 + 2.016$$

$$\text{Fe needed to neutralize free acid} = 1{,}710 \times \frac{55.84}{98.08} = 974 \text{ lb.}$$

$$H_2 \text{ evolved as gas} = 1{,}710 \times \frac{2.016}{98.08} = 34 \text{ lb.}$$

$FeSO_4$ added = 974 + (1,710 − 34) = 2,650 lb.
Total weight = 85,500 + 940 = 86,440 lb.

Filter-press sludge:

Carbon and silicon are precipitated from scrap as solid carbon and silica in a sludge.

Carbon = 0.5 per cent = 974 × 0.005 = 4.8 lb.

$$\text{Silicon} = 0.6 \text{ per cent} = 974 \times 0.006 \times \frac{60}{28} = 12.3 \text{ lb.}$$

Total sludge = 17.1 lb.

Water removal:

Ferrous sulfate heptahydrate

as $FeSO_4$ in original pickling liquor	21,375 lb.
as $FeSO_4$ added by neutralization	2,650 lb.
Total	24,025 lb.

$$\text{as } FeSO_4.7HO = 24{,}025 \times \frac{278.01}{151.90} = 44{,}000 \text{ lb.}$$

Neutralized liquor .... 86,440 lb.
Therefore, water to be removed is 86,440 − 44,000 = 42,440 lb.
Crystals from centrifuge contain 5 per cent water
Therefore, weight of crystals from centrifuge is

$$44{,}000 \times \frac{1}{1.00 - 0.05} = 46{,}310 \text{ lb.}$$

Then, water to be removed in drier is 46,310 − 44,000 = 2,310 lb.
And water to be removed in evaporators = 40,130 lb.

Mother liquor:

Solubility of heptahydrate at 169°F	198.5 g. per 100 g. H_2O
at 75°F	73.8 g. per 100 g. H_2O
Crystals removed	124.7 g. per 100 g. H_2O

$$\text{Mother liquor weighs } 44{,}000 \times \frac{73.8}{100 + 24.7} = 61{,}320 \text{ lb.}$$

$$FeSO_4.7H_2O \text{ in mother liquor} = 61{,}320 \times \frac{73.8}{173.8} = 26{,}038 \text{ lb.}$$

$$FeSO_4 = 26{,}038 \times \frac{151.90}{278.01} = 14{,}217 \text{ lb.}$$

Centrifuged crystal mass:

2,310 lb. water on centrifuged crystals hold in solution $FeSO_4.7H_2O$ equal to $2{,}310 \times \frac{73.8}{173.8} = 1{,}704$ lb.

Therefore, dry crystals = 44,000 − 1,704 = 42,296 lb.
And mother liquor on crystals = 2,310 + 1,704 or 4,014 lb.

C. Proposed Equipment Flow Sheet.

The waste pickling liquor should be placed in storage to allow for several days' accumulated supply and to mix with mother liquor from the centri-

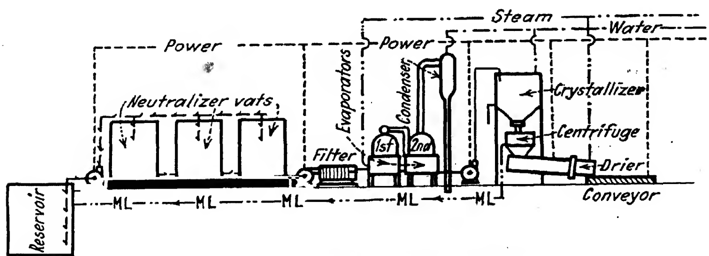

FIG. 43.—Equipment flow diagram for ferrous sulfate recovery.

fuges. This mother liquor remains constant in quantity from day to day, serving as a carrier for the ferrous sulfate daily processed. From the reser-

voir the liquor is to be pumped to neutralizing tanks, where scrap iron is added for neutralization, the hydrogen being allowed to go to waste. After remaining in contact with an excess of iron for 48 hr., the neutralized liquor is to be pumped through a filter to remove insoluble impurities. The clear liquor is then to be evaporated in a double-effect evaporator to saturation at 169°F., after which it is to be pumped into a crystallizer and cooled down to 75°F. It is then to be centrifuged, the wet crystals passed through a rotary drier and thence to storage, while the swing-off liquor is returned as the mother liquor to the storage reservoir.

On the basis of this plan of procedure, the equipment flow sheet of Fig. 43 has been set up.

D. Material Balance (Basis: 24-hr. Operation).

Reservoir.

Entering		*Leaving*	
New liquor		As liquor	
$FeSO_4$	21,375 lb.	$FeSO_4$	21,375 lb.
H_2O	62,415		26,038
H_2SO_4	1,710	H_2O	62,415
Total	85,500 lb.		35,282
Mother liquor		H_2SO_4	1,710
$FeSO_4$	26,038 lb.	Total	146,820 lb.
H_2O	35,282		
Total	61,320 lb.		
Grand total	146,820 lb.		

Neutralizing tanks.

Entering		*Leaving*	
As liquor		As liquor	
$FeSO_4$	47,413 lb.	$FeSO_4$	47,413 lb.
H_2O	97,697		2,650
H_2SO_4	1,710	H_2O	97,697
Total	146,820 lb.	Total	147,760 lb.
As scrap iron		As sludge	
Fe	974 lb.	Sludge	17 lb.
Impurities	17	Total	147,777 lb.
Total	991 lb.	As H_2	34
Grand total	147,811 lb.	Grand total	147,811 lb.

Filter presses.

Entering		*Leaving*	
As liquor	147,760 lb.	As liquor	147,760 lb.
As sludge	17	As cake	17
Total	147,777 lb.	Total	147,777 lb.

Evaporators.

Entering		*Leaving*	
As liquor		As liquor	
$FeSO_4$	50,063 lb.	$FeSO_4$	50,063 lb.
H_2O	97,697	H_2O	57,567
Total	147,760 lb.	Total	107,630 lb.
		As vapor	
		H_2O	40,130 lb.
		Total	147,760 lb.

Crystallizers.

Entering		*Leaving*	
As liquor		As heptahydrate crystals	
$FeSO_4$	50,063 lb.	$FeSO_4$	23,130 lb.
H_2O	57,567	H_2O	19,166
Total	107,630 lb.	Total	42,296 lb.
		As liquor	
		$FeSO_4$	26,958 lb.
		H_2O	38,376
		Total	65,334 lb.
		Grand total	107,630 lb.

Centrifuges.

Entering		*Leaving*	
As heptahydrate crystals		As crystalline mass	
$FeSO_4$	23,130 lb.	$FeSO_4.7H_2O$	42,295 lb.
H_2O	19,166	As occluded liquor	
Total	42,296 lb.	$FeSO_4.7H_2O$	1,704 lb.
As liquor		H_2O	2,310
$FeSO_4$	26,958 lb.	Total	46,310 lb.
H_2O	38,376	As mother liquor	
Total	65,334 lb.	$FeSO_4$	26,038 lb.
Grand total	107,630 lb.	H_2O	35,282
		Total	61,320 lb.
		Grand total	107,630 lb.

Drier.

Entering		*Leaving (to storage)*	
As crystalline mass		As dry crystals	
$FeSO_4.7H_2O$	42,296 lb.	$FeSO_4.7H_2O$	44,000 lb.
As occluded liquor		As vapor	
$FeSO_4.7H_2O$	1,704 lb.	H_2O	2,310 lb.
H_2O	2,310	Total	46,310 lb.
Total	46,310 lb.		

E. Flow of Materials.

Material	Weight, pounds	Volume, cubic feet	Volume, gallons
Reservoir			
Pickling liquor	85,500	1,128	8,440
Mother liquor	61,320	790	5,910
Neutralizing tank			
As liquor	146,820	1,918	14,350
Scrap iron	991	2	......
Hydrogen gas loss	34	......	......
Filter press			
Liquor	147,760	1,920	14,350
Sludge	17	neg	......
Evaporator			
Entering liquor	147,760	1,920	14,350
Exit liquor	107,630	1,277	9,304
Exit vapors	40,130	643	5,041
Crystallizer			
Flowable mass	107,630	1,277	9,304
Centrifuge			
Entering mass	107,630	1,277	9,304
Exit crystal mass	46,310	643[1]	......
Exit mother liquor	61,320	790	5,910
Drier			
Entering mass	46,310	643	......
Exit vapors	2,310	37	280
Exit dry crystals	44,000	667[2]	......

[1] Copperas, centrifuged, weighs 72 lb. per cubic foot.
[2] Copperas, dry, weighs 66 lb. per cubic foot.

F. Reservoir Calculations.

Assume storage desired for 3 days, supply of liquor and the mother liquor for 1 day of plant run.

Mother-liquor volume	790	cu. ft.
Pickling liquor, 3 days at 1,128 cu. ft. per day	3,384	
Total liquor	4,174	cu. ft.
Factor of safety, 10 per cent	417	
Desired capacity of reservoir	4,591	cu. ft.

Assume circular reservoir desired, to be built partly below ground level, with acidproof brick lining, backed by common brick, diameter equaling the depth, curb 1 ft. above ground level.

$$\text{Volume of reservoir} = \frac{\pi d^2 h}{4} = \frac{\pi d^3}{4} = 4{,}591 \text{ cu. ft.}$$

Then $d = 18.002$ ft.
Therefore, diameter of reservoir = 18 ft.
and depth (h) = 18 ft.

Excavation $= \pi \times 9 \times 9 \times 17 = 4{,}325$ cu. ft.
$= 160$ cu. yd.

Bricks. Volume $= \dfrac{2 \times 4 \times 8}{1{,}728} = \dfrac{1}{27}$ cu. ft. $= a$.

Let t = thickness, or $\dfrac{1}{3}$ ft.

Then side of reservoir requires: $\dfrac{\text{Volume bricked up}}{\text{Volume of brick}} = \dfrac{2\pi d/2th}{a}$

and floor of reservoir requires: $\dfrac{\text{Volume bricked up}}{\text{Volume per brick}} = \dfrac{\pi(d/2)^2 t}{a}$

Number of common bricks required for side =

$$\frac{2\pi \times 9 \times 18 \times \frac{1}{3}}{\frac{1}{27}} = 9{,}156$$

and for floor $= \pi \times \left(\dfrac{18}{2}\right)^2 \times \dfrac{1}{3} \times \dfrac{1}{\frac{1}{27}} = 2{,}289$

Total $= 11{,}445$

Number of acidproof bricks required for side =

$$2\pi \left(\frac{18 - 0.67}{2}\right) 17.67 \times \frac{27}{3} = 8{,}663$$

and for floor $= \pi \left(\dfrac{18 - 0.67}{2}\right)^2 \dfrac{27}{3}. = 2{,}126$

Total $= 10{,}789$

Allowing for breakage, 2 per cent,
Then, common bricks $= 11{,}445 \times 1.02 = 11{,}670$
and acidproof bricks $= 10{,}789 \times 1.02 = 11{,}005$

Heat loss in reservoir:

Average room temperature.................................. 60°F.
Temperature of incoming pickling liquor... .... 175°F.
Returning mother liquor.................................... 75°F.

Hence, mixed pickling and mother liquor =

$$\frac{(3 \times 85{,}500 \times 175) + (61{,}320 \times 75)}{(3 \times 85{,}500) + 61{,}320} = 156°\text{F.}$$

Heat loss $= \dfrac{Q}{\theta} = UA\Delta t$ (where U is 25[1])

Then $\dfrac{Q}{\theta} = 25\pi 9^2 \times (156 - 60)$
$= 610{,}740$ B.t.u. per hr.

Temperature drop $= \dfrac{24 \times 610{,}740}{256{,}500 + 61{,}320} = 46°\text{F.}$

Therefore, temperature of liquid leaving reservoir is 110°F.

[1] Appendix A, Table VII.

G. Neutralizing Tank Calculations.

Neutralization requires 48 hr. Allow 12 hr. for filling and 12 hr. for emptying or a cycle per tank run of 72 hr. Each tank is to hold ½ day's supply of liquor. Therefore, four tanks will be in the neutralizing stage, one tank emptying and one tank filling, or a total of six tanks.

Assume a volume of scrap iron to be placed in each tank in large excess, and a daily charge of iron consumed in the neutralization added to this residual mass; mass of the excess scrap is to be equal in volume to liquor in tank.

Volume of pickling liquor per 12 hr. $= \frac{1{,}128}{2}$	= 564 cu. ft.
Volume of mother liquid per 12 hr. $= \frac{790}{2} =$	395
Total liquor	959 cu. ft.
Volume of scrap iron (same as liquor)	959 cu. ft.
Necessary volume of tank	1,918 cu. ft.
Allowance for safety, 10 per cent	192
Actual volume of tank	2,110 cu. ft.
	= 15,182 gal.

Selection of tank (see trade catalogues): Available as standard, a Hauser-Stander redwood tank, 3-in. staves, round, 16,000 gal. capacity, diameter 16 ft., height 12 ft., weight 3,400 lb.

Weight of neutralizing tanks:

Tank	3,400 lb.
Pickling liquor	42,750
Mother liquor	30,660
Scrap iron, 959 × 450	431,550
Pitch for lining	140
Total	508,500 lb.
Six tanks, 508,500 × 6	3,051,000 lb.

Heat loss in neutralizing tank:

Temperature of incoming liquid	110°F.
Temperature of scrap iron added	60°F.
Time in neutralizing tank, 48 + 12	60 hr.

Heat loss $= \frac{Q}{\theta} = UA\Delta t$ (where U is 25[1])

$$\text{Then } \frac{Q}{\theta} = 25\pi 8^2 \times (110 - 60)$$

$$= 219{,}920 \text{ B.t.u. per hr.}$$

Or, during period of standing in tanks, 219,920 × 60 = 13,195,200 B.t.u.

$$\text{Weight of iron added} = \frac{991}{2} = 495 \text{ lb.}$$

Heat loss due to iron = 495 × (110 − 60) × 0.1 = 2475 B.t.u.

[1] Appendix A, Table VII.

Heat gain due to heat of formation of ferrous sulfate in neutralization

$$= \frac{(495 - 8) \times 167{,}760}{55.84} = 1{,}467{,}900 \text{ B.t.u.}$$

$$\text{Total heat loss} = 13{,}195{,}200 + 2{,}475 - 1{,}467{,}900 = 11{,}729{,}775 \text{ B.t.u.}$$

$$\text{Temperature drop} = \frac{11{,}729{,}775}{73{,}410 + 431{,}550 + 495} = 23.2°\text{F. or } 23°\text{F.}$$

approximately

$$\text{Temperature of exit liquor} = 110 - 23 = 87°\text{F.}$$

H. Filter-press Calculations.

Sludge to be eliminated per day totals 17 lb. from scrap, with a possible equivalent quantity from extraneous matter. Assuming press to be cleaned and flushed once per week, and the sludge to have a gravity of 1.75, then volume of sludge will be $\frac{34 \times 7}{1.75 \times 62.4} = 2.19$ cu. ft.

Assume an 18-in. press to be used, fitted with 1-in. frames.

$$\text{Number of frames} = \frac{2.19}{1.5 \times 1.5 \times 1/12} = 17.5 = 18 \text{ frames}$$

Selection of filter press (see trade catalogues): T. Shriver & Co. has available cast-iron press with following specifications:

Plate and frame, corner feed, four button, 1 in.

Type 41cd washing	Filtering area, 70.2 sq. ft.
Frames, 18	Operating pressure, 150 lb. per sq. in.
Outside dimensions, 18 by 18 in.	Weight, 2,300 lb.
Capacity, 2.93 cu. ft.	Floor area, 6 ft. 6 in. by 2 ft.

Heat loss in filter press:

Heat loss $= \frac{Q}{\theta} = UA\Delta t$, where $U = 3$[1]

$$\text{Then } \frac{Q}{\theta} = 3 \times 4(1.5 \times 3) + 2(1.5 \times 1.5) \times (87 - 60)$$

$$= 1821 \text{ B.t.u. per hr.}$$

$$\text{Temperature drop} = \frac{1{,}821 \times 24}{147{,}760 + 2{,}300} = 0.3°\text{F.}$$

Temperature of liquid leaving press = approximately 86°F.

I. Evaporator Calculations.

Ferrous sulfate not affected by heat; costs of equipment to be low; single effect normally satisfactory except that repair would occasion shutdown of plant. Suggest two effects, to be operated as multiple effects.

Temperature of incoming feed	86°F.
Temperature at exit, 18-in. vacuum	169°F.
Liquor entering per day	147,760 lb.
Evaporated liquor leaving per day	107,630 lb.

[1] Appendix A, Table VII.

Assume evaporation to be equally divided between the two effects, one-half the temperature drop in each effect, and the specific heat of liquor to be 1.0.

Steam to be delivered at 15 lb. per sq. in. . . . . 249.7°F.
Latent heat of vaporization at 249.7°F. . . . . 945.3 B.t.u.
Temperature drop through both effects. . . . . 80.7°F.
First-effect calculations:

$$\text{Liquor in first effect} = 249.7 - \frac{80.7}{2} = 209.3\text{°F.}$$

Pressure in first effect will be 14 lb. abs. or 1-in. vacuum.
Latent heat of vaporization at 1-in. vacuum = 971.9 B.t.u.
Heat required to raise incoming liquid =
147,760 × (209.3 − 87) × 1.0 = 18,071,048 B.t.u.

$$\text{Heat required for evaporation} = \frac{40{,}130}{2} \times 971.9 = \underline{19{,}499{,}230} \text{ B.t.u.}$$

Total = 37,570,278 B.t.u.

$$\text{Steam requirements} = \frac{37{,}570{,}278}{945.3} = 40{,}802 \text{ lb}$$

Heating area required:

$\frac{Q}{\theta} = UA\Delta t$, where U is 300[1] and Δt is 40.4°F.

$$\text{Then, } A = \frac{37{,}570{,}278}{24 \times 300 \times 40.4} = 129.4 \text{ sq. ft.}$$

Selection of evaporator:

Trade catalogues reveal that a Swenson-Junior evaporator, with 6-ft. tubes, is available; horizontal tubes desired to facilitate cleaning. Tubes are made of admiralty metal, ¾ in. outside diameter, furnished in blocks 12 by 12, or 144 tubes per block.

Surface per lineal foot of ¾-in. outside diameter tubing is 0.1963 sq. ft.

$$\text{Length of tubing needed} = \frac{129.4}{0.1963} = 660 \text{ ft.}$$

$$\text{Number of tubes} = \frac{660}{6} = 110$$

Provide 100 per cent overload, to operate system with single effect while one effect is under repair.
Two blocks of 144 tubes each will suffice.
Total installed tubes = 288
Available area = 288 × 6 × 0.196 = 338 sq. ft.

Second effect:
Second effect is to be same size as first effect.
Liquor in second effect = 147,760 − 20,065 = 127,695 lb.
Temperature of liquor = 169°F.
Temperature difference = 209.3 − 169 = 40.3°F.
Heat input by entering liquor =
0.5 × 127,695 × 49.4 = 3,154,046 B.t.u.

[1] Appendix A, Table VII.

Heat input by latent heat in vapor from first effect $= 20{,}065 \times 966.2$	$= 19{,}386{,}803$
Total	$= 22{,}540{,}849$ B.t.u.
Loss by radiation (10 per cent)	2,254,085
	20,286,764 B.t.u.

Heat required for evaporation:
Latent heat of vaporization at 18-in. vacuum = 996 B.t.u.
Then $20{,}065 \times 996 \times 1.0 = 19{,}984{,}740$ B.t.u.

Heating area required $= \dfrac{Q}{\theta} = UA\Delta t$ (where U is 150[1])

$$\text{Then } A = \frac{19{,}984{,}740 \times 1.1}{24 \times 150 \times 49.4} = 131 \text{ sq. ft.}$$

Cooling water required:
Cooling water supplied at 68°F.
Assume a 5°F. differential.
Then temperature of exit water is $169 - 5 = 164$°F.
Change in temperature of water is $164 - 68 = 96$°F.

$$\text{Water required per day} = \frac{19{,}984{,}740 \times 1.1}{96} = 229{,}000$$

J. Crystallizers.

Crystallizers to be batch type; two needed, welded construction.

Volume of liquid to be handled $= \dfrac{1{,}277}{2}$	$= 639$ cu. ft
Safety factor, 10 per cent	$= 64$
Total	$= 703$ cu. ft.

Dimensions:
Assume cone bottom, angle of 45 deg.; diameter (d) equal to height (h) at side..

$$\text{Then, volume} = \pi \frac{d^2}{4} h + \frac{\pi}{3}\frac{d^2}{4} h$$
$$= \pi \frac{d^3}{4} + \frac{\pi d^3}{24} = 703$$

Therefore, d is 9 ft., and over-all height = 9 + 4 ft. 6 in. = 13 ft. 6 in.

Cooling coils required:
Assume[2] tubes to be standard condenser tubes, ¾-in. outside diameter, inside sectional area, 0.302 sq. in., surface per linear ft., 0.1963 sq. ft., thickness of tubes, 0.065 in.
Two concentric coils, outer row 1 ft. from outer wall, inner row, 2 ft. from outer wall.
Heat to be eliminated in each crystallizer:

$$\text{Heat of crystallization} = \frac{44{,}000}{2} \times \frac{8{,}110}{278.01} = 641{,}570 \text{ B.t.u.}$$

[1] Appendix A, Table VII.
[2] BADGER, W. L., and W. L. MCCABE: "Elements of Chemical Engineering," Appendix V, McGraw-Hill Book Company, Inc., New York, 1939.

Heat content of liquor $= \dfrac{107{,}630}{2} \times (169 - 75) \qquad = 5{,}058{,}610$

Total $\qquad = \overline{5{,}700{,}180}$ B.t.u.

Cooling water supplied at 68°F.
Temperature difference in coils and water = 5°F.
Therefore, temperature of exit water = 169 − 5 = 164°F.
And change in temperature of water = 164 − 68 = 96°F.

Cooling water required per day $= \dfrac{5{,}700{,}180}{96} = 59{,}377$ lb.

$= 951$ cu. ft.

Velocity through pipes $= \dfrac{951}{24 \times 60 \times 60} \times \dfrac{144}{0.302} \qquad = 5.3$ ft. per sec.

Velocity outside of tubes, assume 1 ft. per sec.

Heat transfer, $\dfrac{Q}{\theta} = \dfrac{A\Delta t}{\dfrac{1}{h_1} + \dfrac{L_2}{k_2} + \dfrac{1}{h_3}}$

Where h_1 = internal film coefficient at 5.3 ft. per sec. = 800[1]
k_2, for copper = 218[1]
h_3, external film coefficient at 1 ft. per sec. = 100[1]
L_2, thickness of tube, = 0.0054 ft.

Therefore, $\dfrac{5{,}700{,}860}{24} = \dfrac{A \times 5}{\left(\dfrac{1}{800} + \dfrac{0.0054}{218} + \dfrac{1}{100}\right)}$

And $A = 437$ sq. ft.

Length of tubing needed $= \dfrac{437}{0.196} = 2{,}320$ ft.

Length of tubing in outer row of coils $= 2\pi\left(\dfrac{9-1}{2}\right) \qquad = 25.13$ ft.

Length of tubing in inner row $= 2\pi\left(\dfrac{9-2}{2}\right) \qquad = 21.99$ ft.

Total $\qquad = \overline{47.12}$ ft.

Number of coils $= \dfrac{2{,}230}{47.12} = 47.4 = 48.$

Weight of liquor $= \dfrac{107{,}630}{2} \qquad = 53{,}815$ lb.

Weight of coils $= 2{,}230 \times 0.514 \qquad = 1{,}146$ lb.

Assume crystallizer to be of ⅜-in. thick steel.
The volume of metal in cone and in cylinder

$$= \frac{3}{8 \times 12}\left(\pi \frac{d}{2}\sqrt{\frac{d^2}{4} + \frac{h^2}{4}}\right) + \frac{3}{8 \times 12} \times 2\pi \frac{d}{2} h$$
$$= \frac{3\pi d}{8 \times 12 \times 4}\sqrt{2d^2} + \frac{3\pi d^2}{8 \times 12}$$
$$= 21.7 \text{ cu. ft.}$$

[1] Appendix A, Table VII.

Hence, weight $= 450 \times 21.7$	$= 9{,}765$ lb.
Weight of coil supports and incidentals, estimated	$= 4{,}000$
Total	$= 68{,}726$ lb.

For an agitator,[1] with wooden paddle arms, 45-deg. pitch, 30 r.p.m., the horse power required is 3.

K. Centrifugals Calculations.

Suggests two intermittent-type, self-balancing, suspended-basket, quick-dumping, belt-driven machines. One machine is to be loading, while the other is whizzing; each machine to be capable of 12 charges per hour.

To operate only during day, two 8-hr. shifts.

Charges per day $= 2 \times 8 \times 12 \times 2 = 384$

Nominal load per charge, $= \dfrac{107{,}630}{384} = 280$ lbs.

Liquor per charge $= \dfrac{790}{384} = 2$ cu. ft.

Crystal mass per charge $= \dfrac{46{,}310}{384 \times 70} = 1.6$ cu. ft.

Load volume $= 3.6$ cu. ft.

Selection of machine: Standard size satisfactory; will be 30 in. diameter, requiring 3.3 to 4.0 hp. at 1,100 r.p.m.; weight, 1, 300 lb.

L. Drier Calculations.

Heat requirements:

Assume specific heat to be 1.0; steam temperature, 212°F.

Heat required to raise mass to temperature of steam =	
$46{,}310 \times (212 - 75) \times 1$	$= 6{,}344{,}470$ B.t.u.
Heat required to evaporate water =	
$2{,}310 \times 945.3 \times 1$	$= 2{,}183{,}643$
Total	$= 8{,}528{,}113$ B.t.u.

Steam requirements $= \dfrac{8{,}528{,}113}{945.3} = 9{,}022$ lb.

Assuming drier efficiency of 60 per cent, then steam consumption will be $= \dfrac{9{,}022}{0.60} = 15{,}032$ lb.

Selection: American Dryer, No. 2.. 8 hp. at 1 r.p.m.

M. Auxiliary-equipment Calculations.

Pipe for mother-liquor return; glazed soil pipe.

Returned every 16 hr. . . . . 790 cu. ft.
Liquor discharge per centrifugal batch. . . . . 2 cu. ft.
Assume this is whizzed off in 3 min.:

Flow will be $\dfrac{2}{3 \times 60} = 0.011$ cu. ft. per sec.

[1] PERRY, J. H., "Chemical Engineers' Handbook," 2d ed., p. 1561, McGraw-Hill Book Company, Inc., New York, 1941.

Smallest sized glazed soil pipe is nominal 2 in.; cross section will be 0.022 sq. ft., and, at rate of 1 ft. per sec., this will carry 0.022 cu. ft.

Conveyors: To carry dry $FeSO_4.7H_2O$ from bottom of drier to storage.

Operating 8 hr. per day capacity $= \frac{44{,}000}{67.0 \times 8} = 82.1$ cu. ft. per hr.

Standard equipment available, steel spiral, 6 in. diameter, 30 r.p.m., delivery 90 cu. ft. per hr.

Power formula $= \frac{KCLW}{33{,}000} = 2.5 \times \frac{90}{60} \times 15 \times 67 \times \frac{1}{33{,}000} = 0.11$ hp.

where K = constant, 2.5
L = distance, 15 ft.
W = weight per cubic foot, 67 lb.
C = capacity of conveyor, 1.5 cu. ft. per min.

Pumps:

For pumping liquor from well to neutralizing tanks:

To pump 8 hr. only.

Volume of liquor per minute $= \frac{14{,}350}{8 \times 60} = 30$ gal.

Design for 150 per cent overload, using 75-gal. pump.

Liquid to flow through three ells, and elevate 35 ft., using 2-in. pipe.

Head, at 1.222 sp. gr. $= [35 + 0.21(35 + 24)]1.222 = 57$ ft.

Pump available: Duriron, self-priming, No. 80, series 80–84, belt driven, 2-in. suction and discharge, 10 hp. at 1,750 r.p.m., capacity 15 to 150 gal. per min.

For pumping liquor from neutralizing tanks to evaporator:

Operating 24 hr. per day; centrifugal type.

Capacity $= \frac{14{,}350}{24 \times 60} = 10$ gal. per min.

Design for 100 per cent overload, requiring capacity of 20 gal. per min.

Head, at 1.222 sp. gr. and having one tee, six ells, filter at 30 lb. per sq. in. and an elevation of 10 ft. using 2½-in. pipe $= [10 + 0.02(16 + 48 + 69 + 10)]1.222 = 16$ ft.

Selection: Gould centrifugal pump, No. 3480–1½; motor-driven; 2-in. suction; 1½-in. discharge; capacity 15 to 175 gal. per min.; 1,450 r.p.m.; 2 hp.; weight, 700 lb.

For pumping liquor from evaporator to crystallizers:

Operating 24-hr.; centrifugal type.

Capacity $= \frac{9{,}309}{24 \times 60} = 6.5$ gal. per min.

For 100 per cent overload, capacity = 13 gal. per min.

Head, with one tee, one safety valve, four ells, and 30-ft. elevation using 2-in. pipe $= [30 + 0.001(16 + 16 + 32 + 30)]1.36 = 29$ ft.

Selection: Gould centrifugal pump No. 3085–2; motor-driven; 3-in. suction; 2-in. discharge; capacity 15 to 250 gal. per min.; 1,750 r.p.m.; 2 hp.; weight, 600 lb.

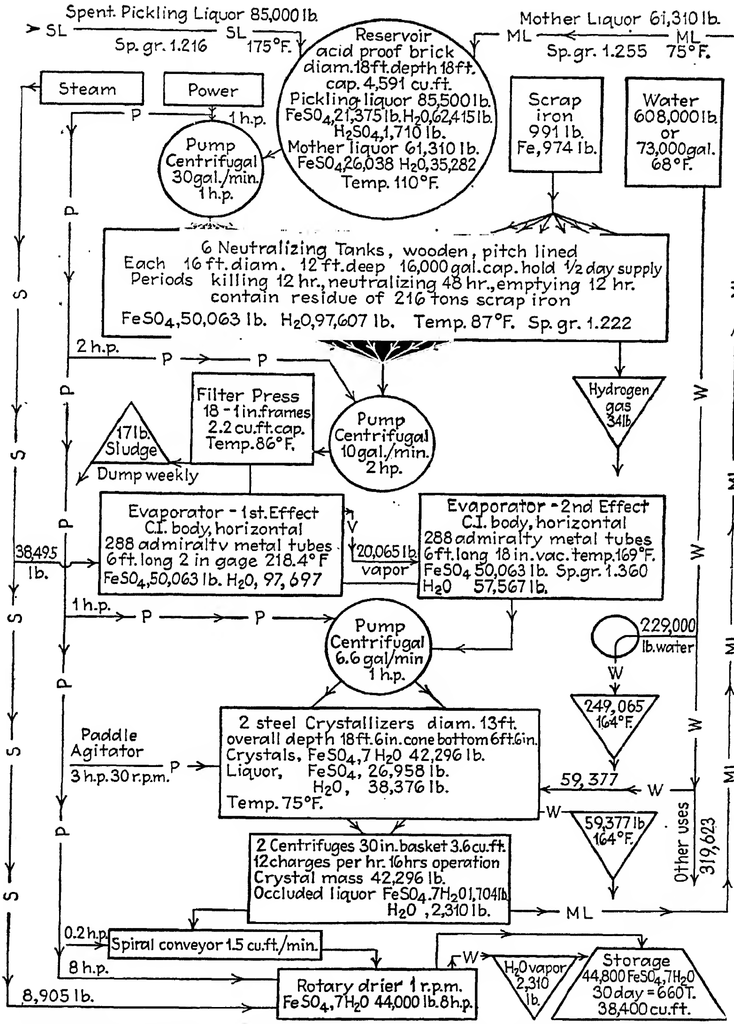

Fig. 44.—Quantitative flow sheet for a ferrous sulfate recovery plant (basis, one 24-hr. day).

N. Steam Consumption.

Evaporator	38,495 lb.
Drier	15,032
Other purposes	29,473
Total	83,000 lb.

O. Water Consumption.

Evaporator	229,000 lb.
Crystallizer	59,377
Total	288,377
	= 34,210 gal.
For washing, sanitation, drinking, and miscellaneous purposes (est.)	38,790
Total	73,000 gal.

P. Power Consumption.

Pump for neutralizers	1 hp.
Pump for evaporator	2 hp.
Pump for crystallizers	2 hp.
For drier	8 hp.
For conveyor	0.2 hp.
For agitator	3 hp.
Total	16.2 hp.

$$\text{Kilowatt-hours per day} = \frac{16.2}{1.34 \times 24} = 250 \text{ kw.-hr.}$$

Q. Storage.

Storage for heptahydrate for 30-day month, with 100 per cent overcapacity for headroom and work space. $FeSO_4.7H_2O$ weighs 67 lb. per cu. ft. Hence, capacity $= 44{,}000 \times 30 \times \frac{1}{67} \times 2 = 38{,}400$ cu. ft.

Floor area for 6-ft. pile $= 44{,}000 \times 30 \times \frac{1}{67} \times \frac{1}{6} = 3{,}284$ sq. ft.

R. Quantitative Flow Sheet.

A summary of the information obtained from the preceding calculations has been entered on the quantitative flow sheet of Fig. 44.

Pictorial Flow Diagrams

Acetic Acid from Wood Distillation, *Chem. Met. Eng.*, **47,** 349 (1940).
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Purifying Cotton Linters, *Chem. Met. Eng.*, **48**, 4—108 (1941).
Raw Sugar From Cane, *Chem. Met. Eng.*, **48**, 6—106 (1941).
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Sulfite Pulp, *Chem. Met. Eng.*, **48**, 8—106 (1941).
Sulfur Mining at Newgulf, *Chem. Met. Eng.*, **48**, 3—104 (1941).
Sulphuric Acid from Refinery Sludge, *Chem. Met. Eng.*, **48**, 5—144 (1941).
Synthetic Amyl Alcohol and Acetate, *Chem. Met. Eng.*, **47**, 493 (1940).
Synthetic Phenol Processes, *Chem. Met. Eng.*, **46**, 221 (1939).
Wet Processed Porcelain, *Chem. Met. Eng.*, **46**, 421 (1939).
Wet Processed Portland Cement, *Chem. Met. Eng.*, **46**, 629 (1939).
Zinc Oxide Production, *Chem. Met. Eng.*, **48**, 2—142 (1941).

CHAPTER X

SELECTION OF PROCESS EQUIPMENT

GENERAL

Standard Equipment.—The value of using standard equipment is well recognized in the chemical engineering field. Performance and service are demanded from all equipment; mistakes in judgment are hazardous—and inexcusable—if service data on like equipment for a similar or related process are available. The experience of others is quite valuable and should be used as fully as possible. Since the good will of the chemical engineer is the aim of all equipment manufacturers, they are desirous of giving service. Much valuable information for the solution of problems is ready for the asking, available from manufacturers who see possibilities of placing orders for equipment. However, they are equally anxious not to enter a field or process wherein they find that their equipment will not give satisfactory service.

Special Equipment.—Although it is a chemical engineering axiom to select standard equipment whenever possible, oftentimes the engineer is confronted with the situation in which his problem requires a special design and probably the use of special materials. In such cases he must draw upon his training and experience to design the requisite equipment. To do this need not awe any designer; he has his specifications; he understands the rules of machine designing; all he needs to do is to apply himself to the task of converting his specifications into a line picture or workshop drawing which the shopmen can convert into a three-dimensional piece of equipment. Much of the equipment for materials handling and for unit processes is standardized, and, whenever such equipment will serve the purpose, it should be selected in preference to special designs. Not only will the first cost be substantially lower, but the duplica-

tion of equipment and the making of repairs on old equipment will be made much easier.

One should assure himself that he has completely exhausted the trade literature for his requirements before he embarks on the design of special equipment. Standard equipment has been tried out and has stood the rigorous test of service. It has produced results and it has gone through long periods of experimentation. Usually it is a result of many modifications of its original design. Standardization not only means a minimum cost in manufacturing, but also it means that a machine built according to standard methods and in standard sizes has usually been given the best of thought in its designing. Under such circumstances, the manufacturers can and do deliver the equipment under a guarantee of satisfactory performance. A new design is as much an experiment for the maker as for the designer; it must stand up under use to acquire recognition for the giving of service. But when the engineer finds himself in a situation demanding the design of new equipment, he should have no hesitancy about executing the commission.

Specifications.—Before one makes a search of the *Chemical Engineering Catalog* and the trade literature files, or before he corresponds with manufacturers of equipment, he should formulate a carefully written specification in which ranges of performance and other requirements have been carefully worked out. The writing of specifications[1] must not be considered a special art, but rather a requisite of every chemical engineer. The specifications should contain all information deemed essential, including composition, physical and chemical characteristics of materials handled, kind and quality of service available, service requirements on the equipment, packing and marking of containers, delivery requirements and quotations. Manufacturers of equipment for chemical engineering use ordinarily supply a form such as that shown in Table 39 in which are included the questions that the individual manufacturer deems sufficient, if answered, to supply him with the information he needs to satisfy the demands. However, as excellent as this service is, the time that would be lost in correspondence may often be saved by sending a well-written specification to the manufacturer.

[1] KIRKBRIDE, C., How to Write a Specification, *Chem. Met. Eng.*, **34**, 670 (1927).

TABLE 39.—SPECIFICATION FORM
INSTANTANEOUS HEATER

If you appreciate the advantages and superior construction of Alberger multi-head heaters, use the following in your next specification.

SPECIFICATION—Alberger Buffalo
Multi-head Heater
Instantaneous Type

TYPE AND SIZE

Furnish and install (in boiler room or elsewhere) as shown on drawings, one Alberger Buffalo Multi-head Heater of the closed water tube type, Size....as manufactured by the Alberger Heater Company, Buffalo, N. Y.

(If horizontal heater is desired)

The heater shall be constructed so as to operate in a horizontal position, and shall be provided with cast iron saddles for support.

(If vertical heater is desired)

The heater shall be vertical and fitted with cast iron legs attached to the tube head, in order that the bottom cover and channel may be removed without taking the heater down.

CAPACITY

The heater shall have ample capacity to heat....gal. of water per hour from....°F. to....°F., when supplied with sufficient steam at....°F.

MATERIALS

Shell, tube heads, water channel, floating heads,
covers, supports, and baffle........................Close grain, gray iron.
Tubes...........Seamless drawn copper, properly corrugated, ¾ in. O.D.
Ferrules....................................Seamless drawn brass.
Gaskets.......................Graphited asbestos sheet, highest quality.

CONSTRUCTION

The heater shall be so constructed that the heating surface shall be entirely accessible without breaking pipe connections; *i.e.*, the heater shall have a separate water channel, with baffles cast integral to direct the flow of water four times through the heater. A baffle placed at the steam inlet shall deflect the steam over the heating surface.

The tubes shall be rolled into a fixed tube head at one end and a multi- or double-floating tube head at the other end. The tubes shall be rolled into the heads by a tube expander and reinforced with hard brass ferrules.

Expansion and contraction shall be accommodated by means of floating multi-heads.

CONNECTIONS

The heater shall be provided with flanged water and steam connections of proper size to flow the quantities of water and steam for the successful operation of the heater. Tapped openings shall be provided for vent, drain blow-offs and relief valve.

TEST

The heater shall be given hydraulic tests of 50 lb. on the steam spaces and 150 lb. on the water spaces.

MATERIALS OF CONSTRUCTION

In order properly to design chemical plants and equipment, the first knowledge to be obtained is a thorough understanding of the chemical and physical characteristics of the materials entering the reaction and of the resulting products. Not only is it necessary to know their characteristics at the beginning and end of the reaction (which is fairly easy to ascertain), but

also during the reaction. Further, the effect of reasonable variation in the quantities of primary and secondary products on the characteristics of the combined mass, as they vary from moment to moment and from one part of the mass to another, must be known. The establishment of the necessary limits in these characteristics, and their control within these limits, is one of the fine points of design.

The chemical engineer cooperates with the chemist in following through a complete batch in the laboratory, in order that the materials of construction for the pilot plant may be determined. In following this batch through, which will be done in the usual containers of glass and porcelain, a study should be made throughout the entire operation of the chemical and physical properties of the material. Another batch should be run in the same apparatus, but arrangements made to introduce into each of the pieces of apparatus a sample of the material that it is proposed to use in the finished plant equipment.

After the batch has been completed, not only should these samples be examined and weighed for corrosion loss, but the product itself should be examined closely to see whether the proposed materials of construction have affected it. When the engineer and chemist have determined these points satisfactorily, the pilot plant should be built—a miniature of the finished plant containing vessels of satisfactory materials that will hold batches of from 10 to 30 gal. In certain cases where it is desired to test the market, the pilot plant can be made slightly larger, and it then becomes in reality a small production unit.

Plan for Selection of Materials.—A brief plan for studying materials for chemical construction has been presented by Calcott and Olive.[1] This is given below as the best plan of attack for solving this problem, which is intimately connected with the design and selection of the proper equipment.

A. Preliminary selection.
1. Experience.
2. Manufacturers' data.
3. Special literature.
4. General literature.
5. Availability.
6. Safety: mechanical and physical properties.

[1] Calcott, W. S., and T. R. Olive, *Chem. Met. Eng.*, **39**, 477 (1932).

7. Preliminary tests by standard laboratory methods as check on deductions from experience, literature and opinion.

B. Laboratory testing.

1. Revaluation of apparently suitable materials, with test pieces included in laboratory runs of the proposed processes.

C. Application of data and final selection.

1. Interpret laboratory results and other data in terms of plant operation, giving consideration to:
   - *a*. Presence of air in equipment.
   - *b*. Possibility of impurities.
   - *c*. Segregation of alloy constituents.
   - *d*. Fabrication method.
   - *e*. Avoidance of electrolysis.
   - *f*. Effect of temperature.
   - *g*. Effect of method of heating.
   - *h*. Effect of agitation.
2. Compare economic features of apparently suitable materials.
   - *a*. Material cost.
   - *b*. Production cost.
   - *c*. Probable life.
   - *d*. Lost-time costs.
   - *e*. Cost of product degradation.
   - *f*. Liability to special hazards.
3. Determine need for semiworks check of data.

Selection Charts and Tables.—The multiplicity of new plastics and new alloys and the more rigid selection of materials of construction for chemical processing, added to the already large number of the older materials, necessitates tables and charts for guidance even for the older construction designers. Table 40 is a chart of manufacturer's recommendations in the field of nonmetallic materials, while Table 41 attempts to present the recommendations for a few of the common metallic materials and industrial products handled. Blank spaces are not indications of rejections or unsafe use, often meaning no data at present available. Unsafe use is indicated by a cipher (0); caution is indicated by a small letter (c) in Table 40 and a slant line (/) in Table 41. Recommended materials in both tables are indicated by a cross (X). Since the chart is limited in the materials listed, and since the classification does not imply a guarantee of service ability, consultation of manufacturers' bulletins and with representatives should be resorted to for plant application of any material.

Recommended Sources of Information.—In addition, an excellent set of 74 individual chemical commodities charts, listing

the various pieces of equipment used in the processing with the correct material of construction can be found in *Chemical & Metallurgical Engineering*, **41** (1934) in monthly installments.

The same magazine has carried on a series of supplements on materials of construction for chemical engineering equipment, convenient tables on materials of construction and their application have been compiled by Lee and Calcott in Sec. 18 of Perry's "Chemical Engineers' Handbook."

EQUIPMENT

Study of Types for Service.—A careful review of the principles of chemical engineering is always necessary in the study of equipment for special service. With a good background in the principles, the equipment designed to handle the specific operations involved is next studied in detail. A review of a number of the unit operations and their equipment is given in the following subdivisions.

Selection of Types for Service.—Selection of the types for service, after a careful study, depends upon judgment and experience. Often several types are available and satisfactory. Then costs, operation difficulties, maintenance, labor, etc., are weighed in the balance before selection is made.

MATERIALS HANDLING

General.—Mechanical handling in the operation of chemical plants is an extremely important function the value of which can rarely be overemphasized. To assure lowest cost of operation, mechanical handling should be substituted for manual handling whenever it can be justified. This unit operation is so highly specialized that the chemical engineer would do well to consult with competent mechanical engineers in selecting the equipment; but the latter cannot do the job alone since special materials of construction will frequently be required, because special hazards, including corrosion, fire, heat damage, explosion and poison, together with special service requirements, must generally be met in the design.

A point that is sometimes overlooked is the function that mechanical handling plays as a coordinator of processes. Not alone does it eliminate manual work, but it also serves to pace

TABLE 40.—RECOMMENDATION TABLE FOR NONMETALLIC MATERIALS OF CONSTRUCTION

Resins and resinoids — Thermoplastic

	Asphaltic and bitumastic. Cold molded	Cellulose acetate	Cellulose acetate-butyrate	Ethyl cellulose	Cellulose nitrate	Acrylic (methyl and methyl meth-)	Coumarone resins	Chlorinated rubber	Butadiene derivatives	Hard rubber	Soft rubber
Acetates (low m.w.)		0	0	0	0	0		0	0	0	0
Acetic acid (dil.)	X	X	X	X	X	X	X	X	X	X	X
(med. conc.)	X	c	X	X	c	c		c	c	X	c
(conc.)		0		X	0	0		0	0	X	c
Acetic anhydride		0		0	0	0			c	X	c
Acetone	0	0	0	0	0	0	0	0	X	0	0
Alcohols (low m.w.)	0	c	0		0	c	c	X	X	c	c
Alums	X				X	X	X	X	X	X	X
Aluminum chloride					X			X	X	X	X
Aluminum sulfate	X				X	X	X	X	X	X	X
Ammonia (gas-liquid)		c	X	X		X		X	X	X	c
Ammonium chloride	X	X	X		X	X	X	X	X	X	X
Ammonium nitrate	X	X			X	X			X	c	c
Ammonium sulfate	X				X	X	X	X	X	X	X
Amyl acetate	0	0	0	0	0	0	0	0	0	0	0
Amyl alcohol	0	X	0	0	0	X	c	X	X	c	c
Amyl chloride	0							c	X	c	0
Aniline				0				0	X	0	0

Resins and resinoids — Thermosetting

	Shellac compounds	Organic polysulfides	Styrenes (polystyrene resins)	Vinylidene chlorides	Vinylchloride acetate resins	Cast phenol formaldehyde	Molded phenol formaldehyde	Phenol furfural plastic	Urea formaldehyde
Acetates (low m.w.)			0	0	0	c	c	c	
Acetic acid (dil.)	X	X	X	c	c	X	X	X	
(med. conc.)	X	X	X	0	0	X	X	X	
(conc.)		X	X	0	0	c	X	c	
Acetic anhydride			c			c	X		
Acetone	0	X	c	0	0	c	c	c	X
Alcohols (low m.w.)	0		X	c	c	X	X	X	
Alums	X	X	X	X	X	c	X		
Aluminum chloride	X		X	X	X	X	X	X	
Aluminum sulfate	X	X	X	X	X	c	X		
Ammonia (gas-liquid)	X		X	X	X	X	X	c	
Ammonium chloride	X		X	X	X	X	X	X	
Ammonium nitrate	c		X	X	X	X	X	X	
Ammonium sulfate	X			X	X	X	X	X	
Amyl acetate	0		0	0	X	c	c	c	
Amyl alcohol	0		X	c	c	X	X	X	
Amyl chloride				X	X	c	c	c	
Aniline						c	c	c	

Cold setting

	Silicaware	Carbon	Casein plastics	Chemical stoneware	Enamel-lined and acidproof porcelain	Glass—industrial	Concrete—unbonded	Concrete—mortar bonded	Transite	Transite—ebonized	Lignin plastics
Acetates (low m.w.)	X	X	X	X	X	X	X	X	X	0	
Acetic acid (dil.)	X	X	X	X	X	X				X	
(med. conc.)	X	X	X	X	X	X				X	
(conc.)	X	X		X	X	X				X	
Acetic anhydride	X	c		X	X	X					
Acetone	X	X	X	X	X	X			X	X	
Alcohols (low m.w.)	X	X	X	X	X	X			X		
Alums	X	X	X	X	X	X			X	X	
Aluminum chloride	X	X		X	X	X					
Aluminum sulfate	X	X	X	X	X	X			X	X	
Ammonia (gas-liquid)	X			X	X	X			X	X	
Ammonium chloride	X	X	X	X	X	X	X		X	X	
Ammonium nitrate	X	X	X	X	X	X	X				
Ammonium sulfate	X	X	X	X	X	X				X	
Amyl acetate	X	X	X	X	X	X	X				
Amyl alcohol	X	X	X	X	X	c			X		
Amyl chloride	X	X	X	X		X					
Aniline	X			X	X	X	X		X	X	

Woods

	Cypress—cold	Cypress—hot	Fir—cold	Fir—hot	Maple—cold	Maple—hot	Oak—cold	Oak—hot	Pine—cold	Pine—hot	Redwood—cold	Redwood—hot
Acetates (low m.w.)												
Acetic acid (dil.)	X		X		X		X		X		X	
(med. conc.)	X		X		X		X		X		c	
(conc.)	c		c		X		X		X		c	
Acetic anhydride												
Acetone												
Alcohols (low m.w.)					X		X					
Alums	X		X		X		c		X		X	
Aluminum chloride												
Aluminum sulfate	X		X		X		c		X		X	
Ammonia (gas-liquid)												
Ammonium chloride												
Ammonium nitrate												
Ammonium sulfate												
Amyl acetate												
Amyl alcohol												
Amyl chloride												
Aniline												

Aniline hydrochloride	X			c				X	X	X	X				X	X		c	c		X	X		X	X	X																
Antimony chloride				c					X												X			X	X																	
Arsenic																																										
Benzaldehyde								0	X	0	0	0			X		X	X	X		X	X		X	X	X	X		X	X		X										
Benzol		c	0	0												0						X																				
Bleaching liquors	X			c					X	X	X						0	0	0		X	X		X	X	X	X			X		c										
Borax	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X		X	X	X	X		X	X		X	c	X	c	X	c	X	X	X	c	c
Bromine									c	c	0			c			c	c	c	c	X	c		X	X	X	X															
Butyl acetate		0	0	0	0	0		0	0	0	0			0	0	0	c	c	c	0	X	X	X	X	X	X	X	X	X	0												
Calcium bisulfite								X	X	X	X						X	X	X		X			X	X	X																
Calcium chloride	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	c	c	c		X	X		X	X	X	X		X	X		X		X		X		X		X		c
Carbon disulfide	0	0	0	0	X	X		c	X	0	0	c			0		X	X	X		X	X		X	X	X				X												
Calcium hypochlorite	X							X	X	X	X		X	X		X	0	0	0		X	X		X	X	X	X					0		0		0		0		c		0
Carbon tetrachloride	0	X	c		X	X		c	X	0	0	0	c	0	X	X	X	X	X		X	X		X	X	X	X		X													
Carbonic acid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	
Casein		X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X		X													
Chloracetic acid				c				X	X	c	c		X	X				X	X					X	X	X																
Chlorinated organics						c				X				0	0						X			X	X	X																
Chlorine	X	c	c						c	X	c			X	X	X	c	c	c		X	c		X	X	X																
Chlorine water	X	c	c						X	X	X			X	X	X	c	c	c		X	0		X	X	X																
Chlorobenzene													0	0	0						X			X	X	X																
Chloroform	0	0	0	0		0				0	0										X	X		X	X	X																
Chromic acid		0	0	0		0	0	0	0					X	X		0	0	0		X	0		X	X	X																
Citric acid		X	X	c	X	X		X	X	X	X	X		X	X	X					X	X		X	X	X																
Copper chloride (ic)								X	X	X	X	c									X			X	X	X																
Copper sulfate		X	X		X	0		X	X	X	X	X					X	X	X		X			X	X	X																
Essential oils	0	c	c	0	0	c	0	0	0	c	0	0									X			X	X	X																
Esters	0	0	0	0	0	0		0	0	0	0			0	0	0	c	c	c		X	X	X	X	X	X	X	X	X	0												
Ethers	0	0	0	0	0	0		0	0	0	0			0	0	0	c	c	c		X	X	X	X	X	X	X	X	X	0												
Ethyl acetate	0	0	0	0	0	0		0	0	0	0			0	0	0	c	c	c		X	X	X	X	X	X	X	X	X	0												
Ethyl alcohol	0	X	c	c		c		X	X	X	X	0	c	X	X	X				X	X	X		X	X	X		X	X									X				
Ethylene chlorhydrin	c	0	0					c	c	c	c				c		c	c	c		X	c		X	X	X						X									X	
Ethylene dichloride		0				0		0	0					0	0	0					X	X		X	X	X																
Ethylene glycol		X	X		X	X		c	X	c	c			X	c	c	c	c	c		X	X		X	X	X												X				
Fatty acids	0	X	X		X			0	X	0	0			X	X	X	c	X	c	X	X	X		X	X	X	X	X	X	X		X	X	X	c	X	X	X	X	X	X	c
Ferric chloride	X			c	X			X	X	X	X	X		X	X	X	X	X	X	X	X	0		X	X	X				X												
Ferric sulfate	X			c	X			X	X	X	X	X		X	X	X	X	X	X	X	X	0		X	X	X				X												
Ferrous chloride	X				X			X	X	X	X	X			X	X	X	X	X	X	X	X		X	X	X				X												
Ferrous sulfate	X				X			X	X	X	X	X			X	X	X	X	X	X	X	X		X	X	X				X												
Fluosilicic acid								X	X	X	X										0			0	0	0																
Formaldehyde	X	0	X		X	X	X	X	X	X	c	X			X	X				X	X	X	X	X	X	X	X			X												
Formic acid				c				X	X	X	c	c		X	X	X	X	X	X	X	X	X	X	X	X	X																
Fruit juices									X	X	c										X			X	X	X																

TABLE 40.—RECOMMENDATION TABLE FOR NONMETALLIC MATERIALS OF CONSTRUCTION.—(*Continued*)

	Resins and resinoids																			
	Thermoplastic										Thermosetting									
	Asphaltic and bitumastic. Cold molded	Cellulose acetate	Cellulose acetate-butyrate	Ethyl cellulose	Cellulose nitrate	Acrylic (methyl and methyl meth-)	Coumarone resins	Chlorinated rubber	Butadiene derivatives	Hard rubber	Soft rubber	Shellac compounds	Organic polysulfides	Styrenes (polystyrene resins)	Vinylidene chlorides	Vinylchloride acetate resins	Cast phenol formaldehyde	Molded phenol formaldehyde	Phenol furfural plastic	Urea formaldehyde
Gasoline		X	X	c	X	X		X	X	c	0			c	c	c	c	c	c	
Glucose								X	X	X	X									
Glue										X	X									
Glycerin		X	X		X	X		c	c	X	X			X	c	c	c	c	c	
Hydrobromic acid	X	X						X	X	X	X	X	X	X	X	X	X	X	X	
Hydrocarbons (aliphatic)			c	c	X	X		X	X	0	0	c	c	X	c	c	c	c	c	X
Hydrocarbons (aromatic)		X	c	c		c			0	0	0	0	0	0	c	c	c	c	c	
Hydrochloric acid (dil.)	X	X	X	c	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
(med.)	X	c	c	0	c	X	X	X	X	X	X	X	X	X	X	X	c	c	c	
(conc.)	X	0	0	0	0	X	X	c	X	X	X	X	0		0		c	X	c	
Hydrofluoric acid										X	X						c	c	c	
Hydrogen peroxide (dil.)	X	c				X			X	c	c		0		c		X	X	X	
(conc.)	c	c				X			X	c	c		0		0		c	X	c	
Hydrogen sulfide									X	X	X		c		X		c	X	c	
Iodine		c							c	c	c									
Ketones		0	0																	

	Cold setting											Woods											
	Silicaware	Carbon	Casein plastics	Chemical stoneware	Enamel-lined and acidproof porcelain	Glass—industrial	Concrete—unbonded	Concrete—mortar bonded	Transite	Transite—ebonized	Lignin plastics	Cypress—cold	Cypress—hot	Fir—cold	Fir—hot	Maple—cold	Maple—hot	Oak—cold	Oak—hot	Pine—cold	Pine—hot	Redwood—cold	Redwood—hot
Gasoline	X	X	X	X	X	X																	
Glucose				X	X	X																	
Glue					X	X			X														
Glycerin	X	X		X	X	X	X																
Hydrobromic acid	X	X		X	X	X																	
Hydrocarbons (aliphatic)	X	X	X	X	X	X																	
Hydrocarbons (aromatic)	X	X	X	X	X	X				X													
Hydrochloric acid (dil.)	X	X	X	X	X	X						X	X	X	c	X	c	X	X	X	X	c	
(med.)	X	X	X	X	X	X						c	0	c	0	c	0	c	0	c	c	0	
(conc.)	X			X	X	X																	
Hydrofluoric acid		X	c	c	c																		
Hydrogen peroxide (dil.)	X	X		X	X	X																	
(conc.)	X			X	X	X																	
Hydrogen sulfide	X			X	X	X	X																
Iodine	X			X	X	X	X																
Ketones																							

Lactic acid		c	X	c						X	c			X							X	X		X	X	X																
Lead acetate																																										
Magnesium chloride	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X												
Magnesium sulfate	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X												
Malic acid								X	X	X	X			X							X			X	X	X																
Mercuric chloride		X																																								
Milk		X	X																																							
Mixed acid	X			0					X	c	c		X	X							X			X	X	X																
Molasses									X															X	X	X	X	X														
Naphtha					X	X		X	X	c	0			c	c	c	c	c	c		X	X	X	X	X	X																
Nitric Acid (dil.)				c				X	X	X	c			X	X	X	c	c			X	0		X	X	X				X												
(med.)				0					0	0				X	c	c	0	0			X	0		X	X	X				X												
(conc.)				0					0	0				X	0	0	0	0			X	0		X	X	X																
Nitrogen oxides									0															X	X	X																
Nitrous acid									X	c	0		X								X			X	X	X																
Oils—animal	0	X	X		X	X		c	c	X	c	X	X	c	X	X	c	X	c		X			X	X	X	X	X	X	X		c	X	X	c	X	X	X	X		X	c
Mineral	0	X	X		X	X		c	c	X	c	X	X	c	X	X	c	X	c		X			X	X	X	X	X	X	X		c	X	X	c	X	X	X	X		X	c
Vegetable	0	X	X		X	X		c	c	X	c	X	X	c	X	X	c	X	c		X			X	X	X	X	X	X	X		c	X	X	c	X	X	X	X		X	c
Oleic acid	0	X	X		X			0	X	0	0			X	X	X	c	X	c	X	X	X		X	X	X	X	X	X	X		X	X	X	c	X	X	X	X		X	c
Oxalic acid	X								X	X	X						X	X	X		X	X		X	X	X	X		X	X												
Phenol		0	0	c		X		X	X	c	0			X			c	c	c		X			X	X	X	X		X													
Phosphoric acid (ortho.)	X	X		0				X	X	X	X				X	X					X	X		X	X	X	X	X	X													
Plating solutions	X								X	X	X				c	c	c	c	c		X	c		X	X	X																
Potassium dichromate										X	X																															
Silver nitrate						X				X	X						c	c																								
Sodium bisulfate	X								X	X	X			X	X	X	c	X	c		X	X	X	X	X	X																
Sodium bisulfite	X								X	X	X			X				X			X	X	X	X	X	X						X		X		X		X		X		
Sodium bicarbonate		X	X		X	X		X	X	X	X	X		X	X	X	X	X	X		X	X		X	X	X	X	X	X													
Sodium borate	X	X	X		X	X		X	X	X	X	X		X	X	X	c	c	c		X				X	X	X		X													
Sodium carbonate	X	c	X		c	0			X	X	X			X			X	X	X		c	X	0	X	c		X		X			X	c	X	X	X	X	X	X	X	c	
Sodium chlorate	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	c	X	X	X	X	X	X	
Sodium chloride		X	X																			X																				
Sodium ferrocyanide									X	X	X						X	X	X		X			X	X	X	X															
Sodium hydrosulfite									X	X	c						X	X	X		X			X	X	X																
Sodium hydroxide (dil.)	X	c	X	X	c	X		X	X	X	X		X	X	X	X	c	c	c	X	0	X		c	0	0				X		X	c	c	0	c	c	0	0	X	X	
(moder.)	X	0	X	X	0	X		X	X	X	X		X	X	X	X	0	0	0	X	0	X		0	0	0				c		c	0	0	0	0	0	0	0	c	0	
(conc.)	X	0	c	X	0			X	X	X	X			X			0	0	0	0	0	X		0	0	0						c	0	c	0	0	0	0	0	c	0	
Sodium hypochlorite	X	c			X				X	X	c			X	X	X	c	c	c			0		X	X	X																
Sodium nitrate		X	X		X				X	X	c						X	X	X		X			X	X	X																
Sodium phosphate (tri)	X			X		X			X	X	X			c			c	X	c		c			X	c	c			X	X												
Sodium silicate	X								X	X	X			X			X	X	X								X															
Sodium sulfide	X								X	X	c			X							c	X	c	X	c	c			X	X		c		c		X		0		X		

TABLE 40.—RECOMMENDATION TABLE FOR NONMETALLIC MATERIALS OF CONSTRUCTION.—(*Continued*)

Resins and resinoids — Thermoplastic

	Asphaltic and bitumastic. Cold molded	Cellulose acetate	Cellulose acetate-butyrate	Ethyl cellulose	Cellulose nitrate	Acrylic (methyl and methyl meth-)	Coumarone resins	Chlorinated rubber	Butadiene derivatives	Hard rubber	Soft rubber
Sodium sulfite									X	X	X
Sulfur dioxide	X			c					X	X	X
Sulfur trioxide	X			0					X	X	X
Sulfuric acid (dil.)	X	X	X	c	c	X		X	X	X	X
(moder.)	X	X	X	0	0	X		X	X	X	X
(conc.)	X	0	0	0	0	0		X			c
Sulfurous acid	X							X		c	c
Sulfuryl chloride											
Tannic acid	X			c						X	c
Tanning extracts	X									X	c
Tartaric acid		X	X					X		X	X
Toluol		c	c	0		c			0	0	0
Turpentine		X						0	0	0	0
Water	X	X	X	X	X	X	X	X	X	X	X
Water (brine) (sea)	X	X	X		X	X		X	X	X	X
Zinc chloride	X			X				X	X	X	X

Resins and resinoids — Thermosetting

	Shellac compounds	Organic polysulfides	Styrenes (polystyrene resins)	Vinylidene chlorides	Vinylchloride acetate resins	Cast phenol formaldehyde	Molded phenol formaldehyde	Phenol furfural plastic	Urea formaldehyde
Sodium sulfite						c	c	c	
Sulfur dioxide				X	X				
Sulfur trioxide				X	X				
Sulfuric acid (dil.)	X	X	X	X	X	c	X	X	X
(moder.)	X	X	X	X	X	c	c	c	
(conc.)			X			0	0	0	
Sulfurous acid						X	X	X	
Sulfuryl chloride							X		
Tannic acid			X			X	X	X	X
Tanning extracts			X			X	X	X	X
Tartaric acid						c	c	c	X
Toluol	0	0	0	c	c	c	c	c	
Turpentine			0						
Water	X	X	X	X	X	X	X	X	X
Water (brine) (sea)	X	X	X	X	X	X	X	X	X
Zinc chloride						c	X	c	

Cold setting

	Silicaware	Carbon	Casein plastics	Chemical stoneware	Enamel-lined and acidproof porcelain	Glass—industrial	Concrete—unbonded	Concrete—mortar bonded	Transite	Transite—ebonized	Lignin plastics
Sodium sulfite	X	X		X	X	X					
Sulfur dioxide	X	X		X	X	X				c	
Sulfur trioxide	X	X		X	X	X				c	
Sulfuric acid (dil.)	X	X	c	X	X	X				X	
(moder.)	X	X	0	X	X	X				X	
(conc.)	X	c		X	X	X					
Sulfurous acid	X	X	X	X	X	X				X	
Sulfuryl chloride	X			X	X	X					
Tannic acid		X	X	X	X	X	X				
Tanning extracts				X	X	X	X				
Tartaric acid	X	X		X	X	X					
Toluol	X	X	X	X	X	X				X	
Turpentine							X		X		
Water	X	X	0	X	X	X	X	X	X	X	
Water (brine) (sea)	X			X	X	X	X	X	X	X	
Zinc chloride		X					X				

Woods

	Cypress—cold	Cypress—hot	Fir—cold	Fir—hot	Maple—cold	Maple—hot	Oak—cold	Oak—hot	Pine—cold	Pine—hot	Redwood—cold	Redwood—hot
Sodium sulfite												
Sulfur dioxide												
Sulfur trioxide												
Sulfuric acid (dil.)	c	c	c	c	X	c	X	c	X	X		
(moder.)	c	c	c	c	c	c	c	c	c	c		
(conc.)	0	0	0	0	0	0	0	0	0	0		
Sulfurous acid							X		X			
Sulfuryl chloride												
Tannic acid							X		X			
Tanning extracts							X		X			
Tartaric acid												
Toluol	c	X	c	X	X	X	X	X	X	X		
Turpentine												
Water	X	X	X	X	X	X	X	X	X	X		
Water (brine) (sea)	X	c	X	c					X	c		
Zinc chloride												

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION[1]

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Acetic acid (crude)	/	/	/	X	X	/	/	X	X	X
Acetic acid (pure)	0	/	X	X		0	0	X	X	X
Acetic acid (vapor)	0	0	/	/		0	0	X	/	X
Acetic anhydride	/	X	X			/	0	/	/	X
Acetone	X	X	X			X	X	X	X	X
Acetyl chloride		X	X							
Acetylene	X				X		/		/	0
Air	X		X			X	X		X	
Aluminum (metal molten)		0	0			X				
Aluminum acetate		X	X							
Aluminum chloride		0	0			/		X	X	
Aluminum fluoride		0	0			/			X	
Aluminum hydroxide		X	X						X	
Aluminum sulfate	0	/	/	/		/	0	X	X	X
Alums	0	X	/	/	/	/	0	X	X	X
Ammonia (gas)	X	X	X	X	X	X	0	X	0	X
Ammonium bicarbonate		X	X	X						
Ammonium chloride	/	/	/	X	X	X	/	X	/	X
Ammonium hydroxide	X	X	X			X	0		0	X
Ammonium nitrate	/	X	X	X		/	0		0	
Ammonium oxalate		X								
Ammonium persulfate		X	X							
Ammonium phosphate (monobasic)	0	X	X			/	0			
Ammonium phosphate (dibasic)	/	X	X			X	/			
Ammonium phosphate (tribasic)	X	X	X			X	0			
Ammonium sesquicarbonate		X	X							
Ammonium sulfate	X	X	/	X	X	X	/	X	X	X
Ammonium sulfide					X					0
Amyl acetate	/		X	X	X	X	/	X	X	
Aniline	X	X	X	X		X				
Aniline dyes	/		X	X	X	/	/		/	
Aniline hydrochloride		0	0		/					
Antimony trichloride		0	0	X						
Arsenic acid	X	X	X			X				X
Asphalt	X		X	X		X	X		X	
Barium carbonate		X	X							
Barium chloride	/	/	/	X	X	X	X		X	
Barium hydroxide	X		X	X	X	X	0		0	
Barium nitrate		X	X							
Barium sulfide	X		X	/		X	0		0	0
Beer (beverage ind.)		X	X	X	X		X	X	X	X

[1] From miscellaneous sources.

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION.[1]—(Continued)

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Beer (alcohol prod.)	X	X	X	X	X	X	X	X	X	X
Beet sugar liquors	X	X	X	/		X	X	X	X	
Benzine	X	X				X	X		X	
Benzoic acid		X	X							X
Benzol	X	X			X	X	X		X	
Black (sulfate) liquor	X		X	X		X	0		0	0
Blast furnace gas	X		X							
Borax	X	X	X	X	X	X	/		/	0
Bordeaux mixture	X			X			X		X	
Boric acid	0	X	X	X	X	/	/	X	X	X
Bromine		/	/					X		0
Butane	X						X		X	
Butanol	X			X			X		X	
Buttermilk		X	X		X					
Butyl acetate	/		X	X			X			
Butyric acid		X	X							
Calcium bisulfate	0	0	X	0	0	0	0		0	
Calcium carbonate	X	X	X			X		X		
Calcium chlorate		X	X							
Calcium chloride	X	X	/	X	X	X	X	X	X	
Calcium hydroxide	X	X	X	X		X	/		/	
Calcium hypochlorite	/	0	/	/	0	/	/	X	/	
Calcium oxychloride		/	/							0
Calcium sulfate		X						X		
Cane sugar liquors	X	X	X	X		X	/	X	/	
Carbon dioxide (dry)	X	X	X	X	X	X	X	X	X	X
Carbon dioxide (wet)	/	X	X	/	X	/	/		/	X
Carbon disulfide	X	X	X	/	/	X	0		0	/
Carbon monoxide		X	X							
Carbon tetrachloride (moist)	/	0	/	X	X	/	/	X	/	X
Carbonated beverages	0	X	X	X		0	/	X	/	X
Casein	X			X	X		X		X	
Castor oil	X	X	X	X	X	X	X	X	X	
Catchup		X	X	X	X					X
Cellulose		X	X	X	X					
Cellulose acetate				X	X			X	X	X
Cellulose nitrate			X	X	X	X				
China wood oil	X	X	X	X	X	X	X	X	X	
Chloracetic acid	0	0	0	/	/		0	X	/	
Chlorbenzol		X	X							
Chlorex	X		0				X		X	

[1] From miscellaneous sources.

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION.[1]—(*Continued*)

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Chloric acid		0	0							0
Chlorine (dry)	X	X		X	X		X		X	X
Chlorine (wet)	0	0	0	/	X		0	X	0	X
Chloroform		X	X	X	X					
Chrome plating bath		X	X							
Chromic acid	/	/	X	/	/	0	0		/	0
Cider		X	X	X						X
Citric acid	0	X	X	X	X	/	/	X	X	X
Coca-Cola sirup		X	X							
Coconut oil	X	X		X	X	X				
Coffee		X	X	X						
Coke oven gas	X		X	X			/		/	
Copper acetate		X	X							
Copper carbonate		X	X							
Copper chloride		/	/							/
Copper cyanide		X	X							
Copper nitrate		X	X							0
Copper sulfate	/	X	X	/		/	0	X	/	/
Core oil	X					X	X		X	
Corn oil	X	X	X	X	X	X	0		X	
Cottonseed oil	X	X	X	X	X	X	0		X	
Creosote (crude)	X	X	X	X		X	/		X	
Cresylic acid		X	X	/	X		0		/	
Cyanogen gas		X	X							X
Developing solution		X	X	X	X					
Dextrose				X	X					
Dichlorethane		X	X							
Dinitrochlorbenzol		X	X							
Diphenyl					X					
Distillery wort		X	X	X		X	X	X	X	
Doctor solution	X		X	X		X	0		0	
Dye wood liquor		X	X	X	X	0			X	
Ethers		X	X	X			X	X	X	
Ethyl acetate	X		X	X		X	X	X	X	
Ethyl alcohol	X	X	X	X	X	X	X	X	X	
Ethyl chloride		X	X	X	X	0				
Ethylene dichloride		X	X	X	X					
Ethylene glycol	X	X	X	X		X	X	X	X	
Fatty acids			X	X	X	/		X		X
Ferric chloride	0	0	0	/		0	0		/	0

[1] From miscellaneous sources.

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION.[1]—(*Continued*)

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Ferric hydroxide		X	X					X		0
Ferric nitrate		X	X							0
Ferric sulfate	0	/	X	/		0	0		/	0
Ferrous chloride	X	0	0	/		X	0	X	/	0
Ferrous sulfate	0	X	0	X	X	/	/	X	X	0
Fluorine		0	0							X
Foamite (acid)	0		/	/		0	0		X	
Foamite (alkaline)	X		X	X		X	0		X	
Formaldehyde	/	X	X	X	X		X	X	X	X
Formic acid	0	/	/	X			0	X	X	X
Freon	X			X			X		X	
Fruit juices (apple, grape, orange)		X	X	X	X	/		X		X
Fuel oil		/	X	X	X	X				
Furfural	X			X			X		X	
Gallic acid		X	X					X		
Gasoline, sour	/	X	X	/		/	0		0	
Gasoline, refined	X	X	X	X		X	X		X	
Gelatin			/	X	X		0		/	X
Glucose	X		X		X		X		X	X
Glue	X	X	X	X	X	X	X	X	X	X
Glycerol	X	X	X	X	X	X	X	X	X	X
Hydrochloric acid	0	0	0	/	/	0	0	X	/	
Hydrocyanic acid	X	X	X	X		X			X	
Hydrofluoric acid	0	0	0	/	/	0	0		/	X
Hydrofluosilicic acid	0	0	0	/		0	0	X	/	
Hydrogen gas	X			X	X		X		X	X
Hydrogen peroxide	0	/	0	X	/	0	0	X	X	0
Hydrogen sulfide, dry	X	/	X	/	X	/	0		0	0
Hydrogen sulfide, wet	/	/	X	0	X	/	0		0	0
Ice cream				X						X
Ink		/	X	X	X		X	X		X
Iodine	X	0	0					X		/
Iodoform		X	X							
Kerosene	X	X		X	X		X		X	
Lacquers	/		X	X			/		X	
Lacquer solvents	/		X	X			/		X	X
Lactic acid		/	/					X		X

[1] From miscellaneous sources.

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION.[1]—(*Continued*)

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Lard	X	X	X			X			X	X
Lead (molten)			/	X						
Lead acetate		X		X						
Lime-sulfur	X		X	X		X	0		0	
Linseed oil	X	X	X	X	X	X	/		X	
Lubricating oil (sour)	/		X	/		/	0		0	
Lubricating oil (refined)	X		X	X			0		0	
Magnesium chloride	/	/	/	X	X		/	X	/	X
Magnesium hydroxide	X		X	X	X		/	X	/	X
Magnesium oxychloride		0	/							
Magnesium sulfate	X	X	X	X	X	X	X	X	X	X
Maleic acid		X	X							X
Mayonnaise		X	X	X		X				X
Meat juices		X	X	X	X					X
Mercuric chloride	/	/	0	/			0		0	0
Mercury	X	X	X				0		0	0
Methanol	X	X	X	X	X	X	X	X	X	X
Methyl chloride		/	/	X						
Milk	/	X	X	/	X	/	0	X	0	X
Molasses	X	X	X	X		X	X		X	
Mustard		X	X	X				X		
Naphthalene sulfonic acid		X	X							
Natural gas	X		X	X		X	/		/	
Nickel chloride		/	/	/	X		/	X	/	
Nickel sulfate		X	/	/	X		/	X	/	
Nitrating acid (sulfuric > 15%)	X	/	/	0	0		0		0	X
Nitrating acid (sulfuric < 15%)	0	/	/	0	0		0	X	0	0
Nitrating acid (nitric < 15%)	0	/	0	0	0		0		0	0
Nitrating acid (acids 1% or less)	0	/	X	0	0		0		0	0
Nitric acid (crude)	0	/	/	0	0		0		/	0
Nitric acid (15–25%)	0	/	X	0	0		0		/	0
Nitrobenzene	X		X							
Nitroglycerin				X					X	
Nitrous acid		X		X	0		X			
Oleic acid	/	X	X	X	X	/	/		X	X
Oleomargarine				X	X					X
Oxalic acid	/	X	/	X		/	/	X	X	X
Oxygen				X				X		X

[1] From miscellaneous sources.

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION.[1]—(*Continued*)

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Palmitic acid	/	X	X	X		/	/		X	
Paraffin		X	X				/		/	
Petroleum (crude)	X		/	X	X	X				
Phenol	X	X	X	X	X	X	/	X	/	X
Phosphoric acid (crude)	/	/	0	0	0	/	0	X	/	X
Phosphoric acid (<45%)	0	X	X	/	/	/	0	X	/	X
Phosphoric acid (cold > 45%)	0	X	X	/	/	/	0	X	/	X
Phosphoric acid (hot > 45%)	0	X	0	0	0	/	0	X	0	
Picric acid (molten)	X	X	X	0	0		0		0	
Picric acid (aqueous)	/	X	X	0	0		0		0	
Pineapple juice				X	X					
Plating solution (chromic)		X	X	X	/					
Potassium bichromate		X	X							X
Potassium bitartrate		/	/							
Potassium bromide		/	/		X					0
Potassium carbonate	/	X	X	X	X	/				
Potassium chlorate		X	X							
Potassium chloride	X	/	/	X	X	X	X	X	X	
Potassium cyanide	X	X	X	X		X	0		0	0
Potassium ferro- and ferricyanides		X								0
Potassium hydroxide	/	X	X	X	X	/	0	X	0	X
Potassium nitrate		X	X	X				X		0
Potassium oxalate		X	X							
Potassium permanganate		X	X	X						
Potassium sulfate	X	X	X	X		X	X	X	X	
Potassium sulfide	/	X	X			/		X		0
Printing ink	/		/	X			/		X	
Producer gas	X		X	X			/	X	/	
Propane	X		X				X	X	X	
Pyrogallic acid		X	X							
Quinine		X	X							
Rayon		X	X	X	X		X			X
Rosin (dark)	X	X	X	X	X		/		X	
Rosin (light)	0	X	X	X	X		0		/	
Sewage	X	X	X	X		X	/		X	
Shellac (orange)	X		X	X			X		X	
Shellac (bleached)	0	X	X	X			X		/	
Sludge acid	0	0	0	/		/	/		X	
Soap solutions	X	X	X	X	X	X	/		/	

[1] From miscellaneous sources.

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION.[1]—(*Continued*)

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Soda ash	X	X	X	X		X	/	X	/	
Sodium acetate		X	X							
Sodium aluminate				X	X	X				
Sodium bicarbonate	/	X	X	X	X	X	/		X	X
Sodium bisulfate	0	X	X	X			/	X	X	
Sodium bisulfite	0	X	X				X	X	X	
Sodium carbonate	X	X	X	X		X	/	X	/	X
Sodium chlorate	/	X								
Sodium chloride	X	/	/	X	X	X	X	X	X	X
Sodium cyanide	X		X	X			0		0	0
Sodium fluoride		/	/							
Sodium hydroxide	X	X	X	X	X	X	/	X	/	X
Sodium hypochlorite	/	/	/		0		0		/	
Sodium hyposulfate	/	X	X	X			0		0	0
Sodium metaphosphate	/		X	X			/		X	
Sodium nitrate	X	X	X			/		X		/
Sodium nitrite				X						
Sodium perborate	/	X	X	X			/		/	/
Sodium peroxide	/	X	X	X			/		/	0
Sodium phosphate (monobasic)	/	X	X	X			X	X	X	X
Sodium phosphate (dibasic)	/	X	X	X			X	X	X	X
Sodium phosphate (tribasic)	X	X	X	X			0	X	/	X
Sodium silicate	X	X	X	X	X	X	0		0	
Sodium sulfate	X	X	/	X	X	X	X	X	X	X
Sodium sulfide	X	X	X	/	X	X	0	X	0	0
Sodium sulfite		X		X		X		X		
Stannic chloride		0	0					X		
Stannous chloride			/							
Starch		X		X	X					
Stearic acid and palmitic acid	/	X	X	X	X	/	0	X	/	X
Strontium nitrate								X		
Sugar juices		X	X	X	X			X		X
Sulfur	X	/					0		0	0
Sulfur chloride	/	0	/	/	/	X	0		0	0
Sulfur dioxide	X	X	X	X		X	X	X	X	0
Sulfur trioxide	X	X	X	X		X	X		X	0
Sulfuric acid (fuming to 98 %)	X	0	/	0	0	/	0		0	0
Sulfuric acid (75–95 %)	X	0	0	0	0	/	0	/	0	0
Sulfuric acid (10–75 %)	0	0	0	/	0	/	0	/	/	X
Sulfuric acid (<10 %)	0	0	0	X	/	/	/	X	X	X
Sulfurous acid	0	/	X	0	0		0	X	/	X

[1] From miscellaneous sources.

TABLE 41.—RECOMMENDATION TABLE FOR METALLIC MATERIALS OF CONSTRUCTION.[1]—(*Continued*)

	Iron and mild steel	Stainless steel (18-8)	Stainless steel (18-8-Mo)	Monel	Nickel	Cast iron (Ni-resist)	Red brass	Bronzes	Aluminum and its alloys	Silver
Tankage	X				/	X				
Tannic acid		X	X	X	X		/	X	X	X
Tar	X	X	X	X		X	X		X	
Tartaric acid	/	X	X	X	X		/		X	X
Toluol	X			X			X		X	
Tin (molten)	X	0	/							
Trichloracetic acid		0	0							
Trichloroethylene	/	X	/	X	X	/	/		/	
Turpentine	X	X	X	X	X	X	/		X	
Urine and urea								X		X
Varnish	/	X	X	X	X		/		X	
Vegetable juices		X	X	X	X					
Vinegar	/	X	X	X	X		/	X	X	X
Viscose	X		X	X	X		X			0
Water (acid mine, oxidizing)	/	X	X	0	0	/	/		/	
Water (acid mine)	/	0	0	X	X	X	/		X	X
Water (boiler feed)	X	X	X	X	X		X		X	
Water (brine)	/	X	/	X	X	X	X		X	X
Water (fresh)	X	X	X	X	X		X		X	X
Water (distilled lab.)	0	X	X	0	/	0	0		0	X
Water (condensate)	X	X	X	X	X		X	X	X	X
Water (sea water)	/	X	X	X	X	X	X	X	X	X
Whiskey and wines		X	X	X	X		/	X	X	X
Yeast		X	X		X			X		X
Zinc (molten)	/	0	0	X						
Zinc chloride	/	/	0	X	X	/	0	X	/	X
Zinc sulfate	/	X	X	X	X	X	/	X	/	X

[1] From miscellaneous sources.

the process, tie together various pieces of processing equipment and frequently to convert batch to continuous operation.

Materials-handling Classification.—Materials-handling equipment is logically divided into continuous and batch types, and into classes for the handling of gases, liquids and solids. Liquids and gases are handled by means of pumps and blowers; in pipes,

flumes and ducts; and in containers such as drums, cylinders and tank cars. Equipment for the handling of solids and semisolids is of a great many types for which a simplified classification

MATERIALS-HANDLING EQUIPMENT FOR SOLIDS

A. Conveyors.

1. Horizontal and inclined movement.
    - *a*. Belt.
    - *b*. Chain or cable.
    - *c*. Chain trolley.
    - *d*. Platform, apron, slat and pan.
    - *e*. Gravity roller.
    - *f*. Live or driven roller.
    - *g*. Bucket.
    - *h*. Scraper, flight, pusher bar, and drag.
    - *i*. Screw.
        - i. Helicoidal.
        - ii. Flight.
        - iii. Ribbon.
        - iv. Paddle.
    - *j*. Drag-line scraper.
        - i. Power hoe.
        - ii. Cable scraper.
    - *k*. Pneumatic.
    - *l*. Solids pumps.
2. Vertical movement.
    - *a*. Bucket elevators, stationary and portable.
    - *b*. Skip hoists.
    - *c*. Chain elevators.
    - *d*. Barrel, package, bag and tray elevators.
    - *e*. Bucket carriers.
    - *f*. Belt elevators.
    - *g*. Spiral chutes.
    - *h*. Roller spirals.
    - *i*. Chutes or spouts.
    - *j*. Pneumatic conveyors.
    - *k*. Water screens.

B. Hoists and cranes.

1. Vertical movement.
    - *a*. Chain hoists.
        - i. Spur gear and differential gear.
        - ii. Electric.
        - iii. Pneumatic.
        - iv. Manual.
    - *b*. Cable and drum hoists.
        - i. Freight and passenger lifts.
        - ii. Suspended.
        - iii. Electric.
        - iv. Pneumatic.
        - v. Manual.
    - *c*. Cranes, stationary.
        - i. Bracket jib.
        - ii. Column jib.
2. Vertical and horizontal movement.
    - *a*. Trolley and tramway hoists, suspended from track.
        - i. Manual.
        - ii. Electric.
        - iii. Pneumatic.
    - *b*. Traveling cranes, above track.
        - i. Motor cranes, suspended cab control.
        - ii. Motor cranes, remote cab control.
        - iii. Manual control.
        - iv. Gantry cranes.
        - v. Bridge cranes.
        - vi. Truck and tractor cranes.
        - vii. Locomotive cranes.

C. Trucks, wheeled.
1. Manual control.
   a. Lift, removable container, box or skid.
   b. Platform, removable or rigid container, box or skid.
2. Power operated.
   a. Lift trucks.
      i. High, trailers, skid platforms.
      ii. Low, trailers, skid platforms.
   b. Platform trucks, trailers, skid platforms.
   c. Special-purpose trucks.
   d. Tractors and trailers.

D. Industrial railways.

based on Montgomery (Perry's "Chemical Engineers' Handbook," Sec. 20) is given above. Montgomery also gives cost data on various types of materials-handling equipment.

Chemical Industry Hazards.—In the main, materials-handling problems in chemical engineering industries do not differ widely from those in other industries except that the existence of seven hazards (Perry's "Chemical Engineers' Handbook," p. 2211) will frequently influence design. These hazards are:

1. Corrosion.
2. Heat damage.
3. Fire.
4. Explosion.
5. Poison.
6. Dust.
7. Pollution.

Corrosion is often the most difficult of these hazards to surmount, and its solution will generally be based on (1) the cheapest type of equipment available, or (2) use of a high first-cost, corrosion-resistant material in the best type of handling equipment, or (3) the use of containers which adequately protect the equipment. Cast-iron liners for moderate temperatures and refractory linings for high temperatures are used to avoid difficulty with heat. Fire and explosion hazards are reduced by grounding the handling equipment where static electricity is likely to develop, by ventilation to reduce dust concentration, by handling materials in containers that eliminate dust scattering, by the use of low-oxygen-content gases in conveying systems, by jarproof conveyances, and by screening to avoid contact with sparks or fire. Poison hazards are reduced by long-distance handling or closed container conveyances. Where food products are handled, sanitary requirements demand covered or sealed containers to prevent pollution—frequently of special materials

of construction—and the employment of easily cleanable equipment with moistureproof bearings.

Selection of Materials-handling Equipment.—Montgomery[1] has stated that the selection of materials-handling equipment depends upon (1) the cost and (2) the work to be done. He recommends that the engineer's choice be checked before purchase by a competent consulting engineer or by an engineer of the company that is to supply the equipment.

Factors that must be considered in choosing materials-handling equipment include:

1. Chemical nature of the material to be handled.
2. Physical nature of the material to be handled.
3. Character of the movement to be made, whether horizontal, vertical, or a combination of the two.
4. Distance of movement.
5. Quantity moved per hour or other unit of time, such as weight, number of pieces, or volume.
6. Nature of feed to handling equipment.
7. Nature of discharge from handling equipment.
8. Nature of flow, continuous or intermittent.

Belt Conveyors.—A belt conveyor consists of a continuous belt supported on idler pulleys, generally arranged to trough the belt, and driven by the application of power to a larger diameter head pulley. The tail pulley is similar to the head pulley except that it is not driven. Most belts are in the range of width from 12 to 60 in.

The world's longest conveyor belt system, consisting of 26 belts with a total belt length of 20.4 miles, running at a speed of 550 ft. per minute, and with a capacity of 1,100 tons per hour, carries construction rock a total length of haul of 9.6 miles from Redding to Coram on the Sacramento River to construct the Shasta Flood Control Dam. About 4,200 hp. are required on the upgrades and about 460 hp. are generated on the downgrades.

In the larger sizes, belt speeds may be as high as 600 ft. per minute, depending on the type of material and the loading. For packaged materials, flat belts are used with speeds up to 200 ft. per minute. Very high capacity is possible with belt conveyors; they offer the further advantage of relatively low maintenance, reasonable power consumption, relatively low cost and con-

[1] Montgomery, G. L., *Chem. Met. Eng.*, **37**, 211 (1930).

tinuous discharge. Belt conveyors may be used on horizontal or inclined runs for handling practically all sorts of solids, ranging from fine powders, through grains and crystals, to large lumps such as coal, ore or stone. Belts are of canvas or canvas-reinforced rubber, while, for special purposes, wire-screen belts and sheet-metal belts have been employed. Special rubber belts have been developed for handling hot materials at temperatures not exceeding 150°F.[1]

Chain Conveyors.—Chains are employed for a great number of purposes in the conveying field. In simple chain conveyors, the chains are dragged through shallow trenches or troughs and serve to convey such materials as hot ashes and hot cement clinker. By the attachment of dogs, blocks or plates, chains and cables may be used for pulling cars up inclines, pulling logs up chutes in paper mills, or dragging bulky material such as coal or stone through troughs. When a chain is supported from trolleys run on an overhead track, it is useful for handling packages and other bulky materials such as tires. Since the track may run both horizontally and inclined, chain trolley conveyors are very flexible.

Attached to platforms, slats, aprons and pans, chains serve to move both packaged and bulk materials at speeds from 30 or 40 to as high as 100 ft. per minute. Apron conveyors are frequently used as feeders for handling coarse material to and from crushers. Such equipment, at low speeds, reduces breakage to a minimum.

For the transportation of bulk materials over paths that may vary anywhere from horizontal to vertical, buckets supported on chains and rollers are often used. Because of the flexibility of the bucket conveyor, both in path and in bucket material, this conveyor is particularly adapted to the handling of abrasive and otherwise difficult materials.

Roller Conveyors.—Rollers for which gravity supplies the motive power and those that are driven are used for the transportation of boxes, packages, etc.

Screw Conveyors.—Essentially, a screw conveyor consists of a strip of metal wound spirally around a shaft that is arranged to rotate with close clearance in a trough. Turning the shaft advances material through the trough by means of the screw action. Consultation with manufacturers is particularly neces-

[1] SEYMOUR, G. N., *Chem. Age (London)*, **9**, 565 (1923).

sary in selecting this type of conveyor. Useful selection tables on conveyors have been presented by Bergmann.[1]

Screw conveyors are of several types, including the double-flight type, which delivers a more uniform stream than the simple type. The cut-flight type is used for materials which tend to pack, or, when placed in a trough having a perforated lining, for removing foreign materials from grain. This type of conveyor also is supplied with mixing paddles and is used for mixing materials during conveying. A similar type, the cut-and-folded conveyor, will thoroughly stir material which passes through it. The ribbon type which, in effect, is similar to the standard screw, except that the center is cut out, is particularly adapted to handling sticky materials which would tend to collect in a standard conveyor at the point where the flights join the shaft.

Drag-line Scrapers.—Conveying equipment of this type employs bucketlike scoops or disks which are moved back and forth by steel cables to drag loose materials from a large storage area, usually outdoors, toward a central elevator or conveyor hopper for subsequent delivery to the plant. Such equipment is used for storing and reclaiming materials like coal or stone.

Pneumatic Conveyors.—The use of air, or occasionally of inert gases, for the sweeping of comparatively light or powdered materials through ducts has come into widespread use in the chemical industry. Pneumatic conveyors are used for handling materials as coarse as shavings and ashes, but their greatest application is for nonflammable materials such as soda ash, phosphate rock and other free-flowing chemicals and chemical raw materials.

Solids Pumps.—The solids pump (Fuller-Kinyon pump) is used to a considerable extent for the handling of pulverized materials such as feldspar and Portland cement. It differs from the pneumatic conveyor in that, in the case of the former, materials are actually blown through the pipe, while in the latter case the material is forced in an aerated condition through a small diameter pipe by the pressure of a screw feeder. This type is more costly than the pneumatic conveyor but employs smaller pipe, requires no cyclone for receiving discharged material and offers increased flexibility in many uses.

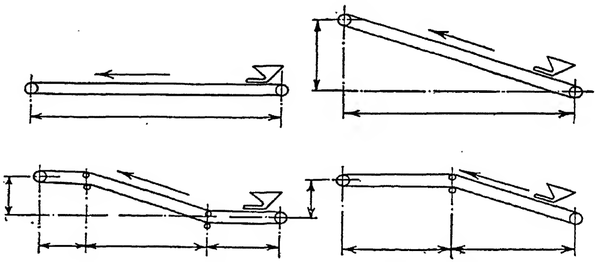
[1] BERGMANN, R. F., Rational Method of Selecting Screw Conveyors, *Chem. Met. Eng.*, **41**, 470 (1934).

Bucket Elevators.—Such elevators consist of a continuous belt or chain traveling between overhead and foot pulleys or sprockets and carrying a number of buckets which scoop material

TABLE 42.—BELT CONVEYOR INFORMATION BLANK

Name of Company..
Street and No...................................City..........State....................
Will installation be at the same place? If not, give location.

Name of material....................................
Condition of material. Wet...........Dry.... ....Hot...........Cold...........Sticky
....
Is there any chemical action on steel?..............................Rubber?...............
Weight per cu. ft............Size of maximum pieces...........Average size of material.................
Percentage of maximum size pieces to average...
Capacity per hour, tons max............Average capacity per hour (tons)............
Hrs. per day operated..
Does conveyor receive material from—Bins...........Elevator...........Crusher ....or other machines?...........Type of feeder used.............................
Will it be fed from one point only? See pages..................Giving type of feed and discharge. Give letter designating type...
Into what does conveyor discharge?...
Fill in dimensions below, in diagram corresponding to installation.



At which end will drive be located...................(Give preference to head end)
Power? Motor.......................Engine........................Line shaft.......................
If we are to include electric motor, give current characteristics.
A. C. or D. C...................Voltage..................Phase..................Cycle..................
Engine. Type..............Speed..............Size pulley..............Diam. shaft..............
Line shaft. Diameter.........................Speed.........................r.p.m.........................
Will conveyor be in building or exposed to weather?
Are we to include supports?.......................Steel.......................Wood.....................
Additional remarks..

LINK-BELT COMPANY

from a boot at the bottom and deliver it at a point slightly below the head pulley or sprocket. Such elevators are generally supplied with a casing.

Skip Hoists.—The skip hoist is a container mounted on wheels and running on a nearly vertical track up which it is pulled by

means of a cable. It is used chiefly for high lifts where accurately measured charges are to be delivered and dumped automatically at definite intervals of time. It is most common in the charging of blast furnaces and vertical lime kilns and in hoisting coal in power plants.

Other Elevators.—Many forms of interfloor elevators are available for the handling of pans, barrels, packages, trays and other material. These generally employ continuous chains, operating vertically, which carry platforms or arms to support the packages. Some of them are devised for automatic pickup and discharge.

As in the case with other manufacturers of process equipment, materials-handling equipment makers supply information blanks to assist in the making of recommendations. A typical blank is shown in Table 42.

SIZE REDUCTION

Size reduction of material is a much used operation in chemical plants. It is accomplished by a wide variety of equipment which, however, all depend upon pressure, impact, attrition or shear, or combinations of these, for their effect. Much energy is required in milling, but only a small part of this, less than 5 per cent, performs useful work. Attempts to raise the efficiency of milling operations have led to a wide diversity of mill types, and to the introduction of closed-circuit grinding wherever practicable. Much recent work has been directed toward the quantitative evaluation of ease of grinding, and to the comparative performance of various sorts of mill. At present, however, it is generally difficult to predict either mill performance or power consumption from a basis of data on similar materials.

Milling goes under many different names, depending on the application. In the case of friable materials, the terms *crushing, grinding, disintegration* and *pulverizing* are employed, and when elastic materials are processed, the reduction in size is known as *shredding, hogging, disintegration, rending* and *abrading*. Milling operations may be carried out in the wet or dry state or by use of an open-circuit or closed-circuit mill. Wet grinding is often employed for the production of very fine products, as in metallurgy, wet-process Portland cement and in paint pigments. Dry milling is used where the presence of water would be harmful

or at least of no particular benefit; examples include the pulverizing of coal and the grinding of cement clinker. When a mill is open-circuited, it means that material is fed into the mill and removed only as it reaches the desired size or finer. When a mill is close-circuited, material is fed rapidly through the mill, the fines being separated outside the mill and the oversize returned continuously with the feed. The advantage of closed-circuit grinding lies in the immediate removal of fines so that they cannot serve to buffer oversize particles and absorb a needlessly large quantity of power. A further advantage is the avoidance of formation of excessively fine particles.

Classification of Size-reduction Equipment.—Many means of classifying size-reduction equipment may be employed. One of these, given below, is based on the size of feed and finished products, but this arrangement is not hard and fast, for the application of particular equipment varies with the materials processed.

Size-reduction Equipment

A. Coarse crushers: Product 2 to 60 in.
  1. Gyratories.
  2. Jaw crushers.
     a. Blake.
     b. Dodge.
  3. Cone.

B. Intermediates: Product $\frac{1}{2}$ to $1\frac{1}{2}$ in.
  1. Rolls.
     a. Single roll.
     b. Multiple roll.
  2. Coffee mills.
  3. Disk crushers, Symonds.
  4. Edge runners.
  5. Stamps.

C. Fine grinders: Product 10 to 200 mesh.
  1. Disk grinders.
     a. Buhrstone mills.
     b. Attrition mills.
  2. Ball, pebble and tube mills.
  3. Rod mills.
  4. Roller mills.
  5. Centrifugal.
     a. Raymond.
     b. Griffith.
     c. Fuller-Lehigh.
     d. Sturtevant.
  6. Multiple roll mills.
  7. Pan mills.

D. Disintegrators.
  1. Squirrel-cage disintegrators.
  2. Hammer mills.
  3. Shredders.
  4. Clod breakers.
  5. Whirlbeaters.

Selection of Crushing and Grinding Equipment.—The following factors are determinants in the selection of equipment for size reduction of materials:

1. Physical properties of material.
   a. Hardness.
   b. Mechanical structure, *i.e.*, whether the material is brittle or fibrous, tough or soft, or thermoplastic.
   c. Moisture content.
   d. Specific gravity.
2. Size of feed and product.
3. Tonnage to be ground.
4. Speed of the mill.
5. Physical properties of grinding of equipment.
   a. Shape and character of lining.
   b. Shape and character of grinding medium.

Mills have so frequently been selected for low maintenance that mill construction is now definitely aimed at long life, ready

TABLE 43.—APPLICATION OF SIZE-REDUCTION EQUIPMENT.

SIZE-REDUCTION EQUIPMENT	PRELIMINARY CRUSHER	INTERMEDIATE CRUSHER	DISINTEGRATOR	FINE CRUSHER	FINE PULVERIZER	LOW FIRST COST	LOW MAINTENANCE	LOW POWER CONSUMPTION	UNIFORM PRODUCT	HANDLES HARD MATERIALS	SOFT TO MED. MATERIALS	DAMP MATERIALS	LARGE CAPACITY	SIMPLE IN OPERATION	ACCESSIBILITY TO PARTS	FREEDOM FROM CHOKING	MIXING AND BLENDING	WET AND DRY MATERIALS	PLASTIC MATERIALS	MATERIALS-FIBROUS
BLAKE JAW CRUSHER	X					X	X	X		X	X	X	X	X	X	X				
DODGE JAW CRUSHER	X					X		X	X	X	X		X	X	X					
GYRATORY CRUSHER	X								X	X	X		X		X	X				
DISC CRUSHER		X				X	X	X	X	X	X		X	X	X	X				
CHILEAN MILL		X					X				X	X		X	X		X			
FLEX.-TOOTH CRUSHER		X				X	X				X	X	X	X	X					
SINGLE ROLL CRUSHER		X				X	X	X			X	X	X	X	X					
SWING HAMMER MILL			X			X	X	X	X	X	X	X	X	X	X			X	X	X
SQUIRREL-CAGE DISINTEGRATOR			X								X		X	X						
ROTARY CRUSHER				X			X		X		X		X							
STAMP MILL				X						X	X			X		X		X		
EDGE RUNNER				X			X		X		X		X	X			X	X		
BUHR STONE MILL					X		X				X			X			X	X		
BALL MILL					X	X	X	X	X	X	X		X	X	X		X	X	X	
TUBE MILL					X		X	X	X	X	X		X	X	X		X	X	X	
ROD MILL					X		X		X	X	X		X	X	X		X	X		
ROLLER MILL					X	X	X	X	X		X	X		X						
RAYMOND-TYPE MILL					X		X	X		X	X			X						
CONICAL MILL					X		X	X	X	X	X		X	X	X		X	X		
SMOOTH DOUBLE ROLLS				X		X	X	X			X	X	X	X	X					
HADSELL-TYPE MILL					X		X	X	X		X		X	X		X	X	X		

disassembly and easy replacement of worn parts. Mills designed for resistance to corrosion have also been made available. In mills subject to a high degree of abrasion, special abrasion-resisting material such as manganese steel and Stellite are employed.

An extensive compilation of information and data on the construction, design, capacity and horsepower requirements of grind-

ing and milling equipment of all sorts has been published by Kanowitz in Perry's "Chemical Engineers' Handbook," Sec. 16. Kanowitz has also compiled information on the industrial applications of milling equipment, giving operating characteristics on a large number of products. The use of air as a conveying medium in grinding mills, for removing the product and for accomplishing drying simultaneously with size reduction, is covered by Kanowitz in a discussion of close-circulating of mills by means of air separators.

Table 43 is an application chart for size-reduction equipment showing classification of types and characteristics of several examples in each type.

Gyratory Crushers.—A gyratory crusher consists of a conical hopper within which a conical spindle rotates with an eccentric motion. Material fed between the hopper and the spindle is pinched, crushed and abraded, and discharged at the bottom in sizes usually not less than ½ in. Gyratory crushers are essentially primary machines, taking feed sizes as large as several feet for the largest dimension. Capacities from 4.5 to 550 tons per hour are available requiring as high as 180 hp.

Jaw Crushers.—Jaw crushers of two principal types are in use, but both are similar in that they employ one fixed and one movable jaw, arranged to pinch and crush material placed in the feed opening. Like the gyratory crusher, jaw crushers will handle feed material of several feet in dimensions and will yield enormous capacities.

Cone Crushers.—Cone crushers resemble gyratories superficially in that an eccentric conical head rotates within a conical hopper. However, such crushers are adapted to finer and more accurate sizing and do not attain the large feed sizes of gyratory crushers.

Crushing Rolls.—Roll crushers are of various types including both single- and double-roll crushers. The rolls are either smooth or corrugated cylinders rotating in a horizontal plane. In the case of single-roll crushers, the material is nipped and crushed against a plate, while in the case of double-roll crushers, material is nipped between the rolls. If more than a single stage of crushing is required, four-roll crushers may be employed. Roll crushers are particularly adaptable to the intermediate milling of such soft materials as coal, shale and phosphate rock. Rolls

are suitable to the production of many crushed products as fine as $\frac{1}{8}$ in. The maximum feed size depends upon the angle of nip, which in turn depends upon the roll diameter. Practically, roll crushers are rarely built to take feed larger than a few inches in size. Depending on the desired reduction, roll crushers are available with capacities of several hundred tons per hour, operating at as high as 300 r.p.m. and requiring 25 hp.

Coffee Mills.—These are attrition mills, consisting of a truncated conical rotor, rotating within a truncated conical casing, both rotor and casing faces being provided with ridges or teeth. Such mills are suitable for handling soft, friable materials, such as coal, coke and tanbark. Maximum feed size is generally not over 6 in.

Edge Runners.—In general, these mills consist of one or more heavy rolls rotating in a pan. This rotation may be accomplished either by rotating the pan or by rotating the horizontal roll shaft about a fixed center. Mills of this type are also known as *wet* and *dry pans*, *Chilean mills* and *chasers*. The grinding is accomplished by the combination of pressure, shear and abrasion. Dry-pan mills generally employ a perforated pan which releases the fine material when ground. Pan mills are used largely in the ceramic industry and for the mixing of plastic masses such as black powder, dynamite and putty. Their use in the latter connection is based on the combined grinding and mixing effect produced.

Buhrstone Mills.—Mills of this type generally employ two wheel-like stones dressed smooth or more frequently cut in grooves, one of which rotates in a horizontal plane in contact with the other. They are largely employed in grinding soft materials, when at the same time such materials are to be incorporated in a liquid medium, as in paint and pigment grinding. These mills vary in diameter from 20 to 36 in., revolving at 27 to 50 r.p.m. requiring 3 to 7.5 hp.

Attrition Mills.—Many types of attrition mills have been devised, one of the most common of which employs two oppositely rotating disks between which the material is fed at the center. The disks 16 to 36 in. in diameter may be either horizontally or vertically disposed operating between 900 and 1800 r.p.m., requiring from 9 to 30 hp., and the material is thrown outward during their rotation and abraded between the oppositely rotating

surfaces. Mills of this type are used for grinding such materials as casein, leather and bark.

Ball, Pebble and Tube Mills.—Such mills reduce by a combination of pressure, impact and attrition. All operate on a similar principle, *i.e.*, that of a cylindrical casing arranged to rotate on a horizontal axis and containing as a grinding medium metal or porcelain balls or quartz pebbles. Mills of this type are used for a wide variety of grinding operations ranging from such hard materials as flint to friable drugs and chemical products The chief difference between a ball and a tube mill is one of shape, the latter being longer and of smaller diameter. Mills of this classification are the type generally employed in large-scale fine grinding, particularly where the grinding is accomplished wet. For dry grinding they may be close-circuited with air separators or screens and for wet grinding with mechanical classifiers. Certain forms of ball mills are divided into sections containing grinding mediums of decreasing size and separated by perforated plates. The purpose here is to accomplish several stages of grinding in one mill. A similar purpose is accomplished by the conical construction employed in the Hardinge mill which effects a grading of the balls from large, at the feed end, to small at the discharge end, as a result of its peculiar shape.

Ball and tube mills rarely operate on feed sizes larger than 2 or 3 in. but are capable of grinding to 200 mesh or finer. Their capacities range upward from laboratory size to several hundred tons per day for a comparatively coarse product.

Rod Mills.—Rod mills are somewhat similar to ball mills except that the grinding medium consists of cylindrical rods which grind the mill charge largely by attrition. Such mills are employed to a considerable extent in the metallurgical industry in cases where uniformity of product in the size range up to 20 mesh is desired. The reduction of cornstalk, cane and wood to uniform fibrous masses in synthetic lumber production is a recent application of the rod mill.

Roller Mills.—Roller mills employ odd numbers of rolls, either three, five or seven, and operate their rolls at increasing speeds from feed to discharge. They are used principally in the grinding of pastes such as paint, ink and chocolate. By reason of the increasing speed from roll to roll, the material follows the faster roll at each point of contact and so progresses from the

feed to the discharge point. Such mills are capable of extremely fine grinding and give a highly uniform product.

Centrifugal Roll Mills.—Several mills secure pressure between a rotating element and a stationary element, on which the first rolls, by means of centrifugal force. Material that falls between the two elements is reduced by an action that is largely compression. These mills are used for fine grinding, producing products as fine as 200 mesh or smaller from comparatively friable materials such as coal, shale and limestone. Such mills have the advantage of small floor space and comparatively low operating and maintenance cost.

Cage Mills.—Such mills consist of two cylindrical cages made of bars, one of which rotates within the other and in the opposite direction. These mills are sometimes referred to as disintegrators. They are particularly suitable for the reduction of fibrous materials or brittle materials which soften when heated. They are also useful for damp and sticky materials. Among their principal uses may be listed tankage, bones and garbage reduction for fertilizer.

Hammer Mills.—Hammer mills find a wide range of usefulness in the chemical industry where various types are used. In most hammer mills, a rotating drum-shaped element carries swinging hammers which beat the material against breaker plates forming part of the cylindrical casing and pound the particles, as they reach the desired size, through a discharge opening covered by a perforated plate, bars or a wire screen. In its various forms, the hammer mill is used for a great many materials, ranging from friable to tough to fibrous. Certain of these mills will reduce to finer than 200 mesh, and, in the coarser crushers, mills having capacities as high as several hundred tons per hour are available.

Shredders.—Shredders are of various forms, generally depending upon a shearing, cutting and tearing action for reduction. They are useful for the disintegration of natural products such as wood or bark. Some forms employ knives for the production of chips. Others use swing hammers. Still others employ disks, rolls or cones. Depending on the type of construction, capacity and performance vary widely.

Effect of Moisture.—Certain materials may contain a considerable percentage of moisture before there is an appreciable

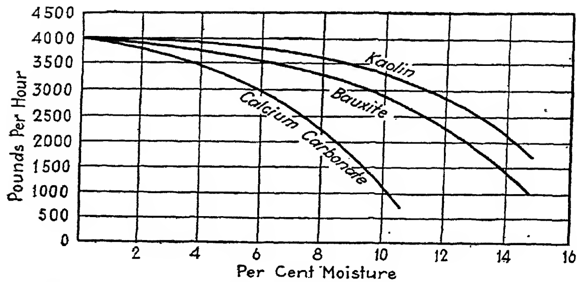


FIG. 45.—Relation between moisture content and capacity in grinding. (*Raymond Bros. Impact Pulverizer Company.*)

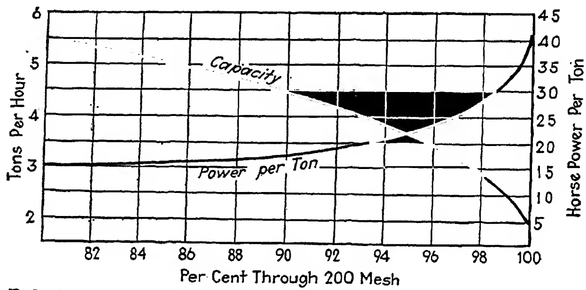


FIG. 46.—Relation between fineness, capacity, and power consumption in grinding. (*Raymond Bros. Impact Pulverizer Company.*)

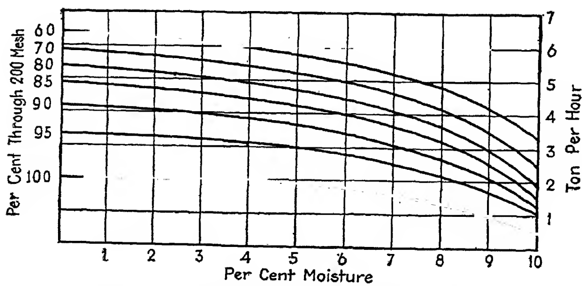


FIG. 47.—Relation between moisture content, fineness, and capacity of grinding. (*Raymond Bros. Impact Pulverizer Company.*)

decrease in mill capacity.[1] In others, increasing moisture content reduces capacity very sharply. This is indicated by the curves of Fig. 45 which show that the capacity with calcium carbonate

TABLE 44.—MILLING INFORMATION BLANK
POWER AND MINING MACHINERY COMPANY

Please fill in answers to the following questions, detach sheet and mail with your inquiry:

...................................193

1. What is the character of the material to be crushed?................

....

2. Is the material inclined to break into flat pieces?....................

....

3. What amount of material, in tons or cubic yards, is to be crushed per hour?..

....

4. Through what size of ring is it desired to pass approximately the entire crushed product?..

....

5. How many and what sizes of product do you wish to produce?........

....

6. Is it desired to return the oversize or rejections to the initial crusher to be recrushed or to a separate crusher for this purpose?.............

....

7. What disposition will be made of the fine screenings?................

....

8. Will storage bins be required and if so what capacity for each size of material?..

....

9. Do you wish us to include in our estimate, power plant for operating crushing plant and what kind would you prefer?....................

10. Is your location a flat or hillside one? If hillside give us profile as nearly as possible with sketch.......................................

....

11. Which system of handling rock for the crusher do you prefer?
    (*a*) Incline and automatic dump cars.
    (*b*) Level proposition with end dump cars and tipple.
    (*c*) Level proposition with side dump cars.
    (*d*) Overhead cable with skips or buckets.
    (*e*) Incline chute.
    (*f*) Incline track with brake.
    (*g*) Bottom dump cars on tramway.
    (*h*) Horse and cart.

....

....

....

....

(Signed).............................

drops off much more rapidly with increasing moisture content than that with either bauxite or kaolin. Figure 46 shows the relation between fineness, capacity and power consumption in the grinding of a material such as barytes in an air separation

[1] KANOWITZ, S. B., *Chem. Met. Eng.*, **32**, 199 (1925).

pulverizer. Figure 47 shows the relation between moisture content, fineness and capacity for various sizes of product.

Because of the effect of moisture on certain materials, it is sometimes desirable to combine drying and grinding in the same apparatus. Certain manufacturers are now supplying air-drying pulverizers in which the conveying air used to remove the product from the pulverizer is heated in a separate furnace. A consideration of the three figures just discussed will often show when it is desirable to employ an air-drying pulverizer.

Data Required.—Since much experience is required in determining the most efficient and economical method of solving a grinding problem, manufacturers of grinding equipment should be consulted. They supply information blanks similar to that shown in Table 44.

MECHANICAL SEPARATION

A large number of unit operations are embraced under the general term of *mechanical separation.* This group is one of the most important employed in the chemical industry. The separations involved may be grouped into five headings as follows:

1. Separation of solids from gases
2. Separation of solids from solids.
3. Separation of solids from solids in liquids.
4. Separation of solids from liquids.
5. Separation of liquids from liquids.

Separation of Solids from Gases

Solids are separated from gases by a variety of methods including settling, centrifugal force, filtration, impingement on particles of liquid or on wetted or sticky surfaces, and by means of electrostatic precipitation. These methods are covered by Anderson in Perry's "Chemical Engineers' Handbook," Sec. 15. Such separation methods are employed to eliminate waste solids from contaminated air, to separate valuable solids from conveying air in materials-handling equipment, and to separate pulverized materials from conveying air in air-swept pulverizers. As an example of the information required by dust-collection-equipment manufacturers, Table 45 is given herewith.

TABLE 45.—DUST COLLECTION DATA SHEET

CONDENSED QUESTIONNAIRE

Fill in and return to Blaw-Knox Company, Dust Collector Division, Pittsburgh, Pa.

1. Name.................................Date................
2. Address..
3. Kind or nature of dust...................................
4. List of the sources of the dust where collection is desired. Give size and description of machines where possible.

....
....
....

5. Description of dust:
   (a) Is it moist or dry?..................................
   (b) Its approximate temperature..........................
   (c) Percentage of moisture by weight.....................
6. Can you and are you sending us layouts or sketches showing location of dust sources and available space fcr locating dust collectors?.......

....

7. Electrical characteristics of your plant.....................

....

8. If electrical power not available, how can fan and vibrator be driven?

....

9. What is object of installation of equipment? Is it to improve:
   (a) Plant conditions.....................................
   (b) To recover valuable substances.......................
   (c) To free surrounding territory from objectionable emanations......
10. Can you send us a sample of dust to be handled?..................
11. Please describe its physical and chemical characteristics..............

....

12. Do you want an engineer to call?..............................

All information furnished us will be held strictly confidential and used only to enable us to solve your problem.

If you have any additional information that you think can help us understand your problem, please let us have it. Remember that drawings will make it easier for us to understand your plant layout.

SEPARATION OF SOLIDS FROM SOLIDS

Solids may be separated from solids in the dry state by a variety of methods including:

1. Screening.
2. Magnetic separation.
3. Electrostatic separation.
4. Air separation.

Screening.—The method most used for grading dry, solid particles is screening, which in the finer sizes is also known as sieving and bolting. In every case, a woven fabric of cloth or metal, or a perforated metal plate, is employed to hold back particles above a given size and permit the passage of all particles smaller than the given size. In every type of screen, it is necessary by some means to accomplish motion of the material across the screen surface and, in most cases, to keep the material in such a state of motion that every particle has an opportunity to

pass through if it is sufficiently small. These requirements have given rise to a large number of screen types (see Donaldson, Perry's "Chemical Engineers' Handbook," Sec. 15), a simple classification of which may be given as:

1. Grizzlies.
2. Trommel screens.
3. Fine screens.
   a. Shaking and gyrating screens.
   b. Vibrating screens.
   c. Rotating screens.
   d. Impact screens.

Grizzlies.—Grizzlies are made in various forms, the most usual type being a slanting deck of parallel bars which may be either stationary or shaking. Such screens are used for large tonnages of large-size materials. Coal, coke, and crushed stone are materials frequently separated over grizzlies.

Trommel Screens.—These screens are used largely for gravel and crushed stone and consist of cylinders mounted on a slightly sloping axis about which they rotate. The cylinder surface is made of screen cloth or perforated metal. Customarily two or more trommels with progressively finer openings are used in series to effect a grading into several sizes. Trommel screens operate at low speed between 14 and 21 r.p.m. and are employed for relatively coarse material.

Shaking and Gyrating Screens.—In an effort to duplicate the motion of hand screening, many screens are produced with mechanism to impart a shaking or gyratory motion to the screen deck. Such screens are available with from one to four decks, producing from two to five sizes of graded product with capacities as high as from 2 to 8 tons per square foot per day. A frequent method of avoiding blinding in such screens is to place a number of rubber balls on each deck so that the impingement on the screen surfaces will knock loose any material that tends to stick.

Vibrating Screens.—Vibration of the screen cloth is employed in a number of types of screen to produce motion of the material. Some types employ mechanical vibration through the use of rotating ratchets, and others use electromagnets. In one type, which is intermediate between the shaking and the vibrating screen, the entire screen deck is given a rapid shaking motion by

means of an eccentric or unbalanced weight on a rotating shaft. Vibrating screens are capable of screening as high as 11 tons per square foot per day. In still another type, the entire screen deck is given a rapid throwing motion at an angle oblique to the surface by means of electromagnets. These last two types are perhaps better classified as impact screens. All these types are suitable for comparatively fine screening and large capacities. The usual lower limit for the fine product from such a screen is 20 to 50 mesh.

Table 46.—Relation between Screen Aperture and Size of Largest Particle in Product from Various Types of Screens[1]

Size of particle, inches	Size of aperture, inches					
	Round			Square		
	Flat surface	40- to 45-deg. screen	Revolving screen	Flat surface	40- to 45-deg. screen	Revolving screen
0.25	0.35	0.50	0.50	0.28	0.38	0.40
0.375	0.55	0.75	0.75	0.45	0.57	0.60
0.50	0.75	1.0	0.88	0.62	0.75	0.75
0.75	1.0	1.50	1.25	0.81	1.15	1.15
1.0	1.5	2.0	1.88	1.15	1.50	1.50
1.25	1.75	2.50	2.25	1.40	2.0	1.75
1.5	2.0	2.75	2.5	1.62	2.25	2.0
1.75	2.25	3.25	3.0	2.0	2.75	2.5
2.0	2.75	3.75	3.5	2.25	3.0	2.75
2.5	3.5	4.75	4.0	2.88	3.75	3.25
3.0	4.25	5.50	5.0	3.5	4.5	4.0
3.5	5.0	6.50	6.0	4.0	5.25	4.75
4.0	5.75	7.50	7.25	4.75	6.0	6.0

[1] Reproduced by permission from A. F. Taggart, "Handbook of Ore Dressing," p. 516, John Wiley & Sons, Inc., New York, 1927.

Rotary Screens.—Somewhat similar to trommel screens in their construction, but intended for finer screening, are the rotary screens, sifters and bolters which employ fine mesh wire cloth or silk as the screening medium. Such screens generally use a stationary brush for the screening surface which assists in preventing blinding of the openings. Capacities approximating 1 ton per square foot per day are possible.

Screen Cloth.—Many thousands of different meshes, sizes, grades and weights of screen cloth are available, manufactured from a variety of different materials. Although the first consideration is the size of opening, corrosive and abrasive characteristics of the material are also of paramount importance. In determining a suitable screen cloth, the following characteristics of process and screen should be considered:

Product	Screen
Size of product.	Size of mesh or opening.
Weight and abrasive nature of product.	Wire diameter or thickness.
Capacity or output.	Size of screen deck.
Material, dry or wet.	Plain or twilled weave.
Chemical characteristics.	Kind of metal or alloy.

In specifying the size of screen opening, it should be noted that a square opening has a larger area than a round opening when the diameter of the latter is equal to the side of the square. Table 46 gives the relation between the screen aperture and the size of the largest particle in the product, produced by various types of screen with both round and square openings. It will be noted that the particle size approaches much closer to the aperture size in the case of the square screen. Table 47 presents a manufacturer's information blank for vibrating screens.

Magnetic Separation.—The simplest form of magnetic separator consists of a chute in which the material comes in contact with one or more permanent magnets or an electromagnet. Other types employ a magnetized pulley over which material is carried on a belt. Recently developed high-intensity magnetic separators make use of an intense magnetic field concentrated on revolving laminated rotors. Magnetic separators, in the less powerful types, are used for removing tramp iron from process materials and for separating magnetic and nonmagnetic metals. High-intensity separators are capable of removing material of such low magnetic susceptibility as to be almost nonmagnetic. Such separations include mica from feldspar and other purifications of nonmetallic minerals.

Electrostatic Separation.—The Huff separator is the only electrostatic separator for solids and should not be confused with the Cottrell precipitator for separation of gas dispersoids. It is used to a small extent in the separation of nonmagnetic materials.

TABLE 47.—LEARN WHAT THE HUM-MER ELECTRIC SCREEN WILL DO ON YOUR MATERIAL

FILL OUT THIS FORM AND SEND THE SAMPLES REQUESTED

Screen analyses and, if necessary, capacity tests will be made with your samples.

A report of the results and a recommendation as to equipment will be forwarded to you.

If Hum-mer capacity tests are made, samples of the screened products will be forwarded. No charge will be made for this service.

The material is..............................and is used for....................................

Samples sent (charges to be prepaid)............................via: Check: Mail ☐ Express ☐ Freight ☐
(DATE)

Mark samples as below	Amt. desired for test	Present capacity (Tons per hour)	Capacity desired (Tons per hour)	Description or specification as to fineness	Mesh and wire used at present
(*a*) To be screened	50 lb.	....	....	all pass.....	
(*b*) 1st product	1 lb.	....	....	....	....
(*c*) 2nd product	1 lb.	....	....	....	....
(*d*) 3d product	1 lb.	....	....	....	....

Material will be screened Dry............ (Check) Damp............% (Moisture) Wet............ (Check) With water............ (Check)

What improvement is desired?...

....

Crushers used.. (Name and Type) .... (Number)

Screens now in use..... (Name and type) (Number) (Screening angle)

Headroom available.......................Floor space available................................

(A rough sketch showing floor space and headroom will help—Use back of sheet)

Remarks:

If electric power available, specify volts..............cycle..............phase..............

Name of Company..

Street Address..

City and State..

Date..............................194.... By..................

Title or Position.

Its action depends on the fact that certain materials will assume a static charge in passing over a highly charged surface and will be attracted out of the line of fall by an oppositely charged surface. Unfortunately, the performance with various materials can be determined only by test.

Air Separation.—The size grading of particles in dry grinding operations is often accomplished by taking advantage of the different rates of fall of different sizes of particles in an air stream.[1] Sometimes the particles are also subjected to centrifugal force, but the principal separation is accomplished by differences in settling rates. This subject is covered by Kanowitz (Perry's "Chemical Engineers' Handbook," Sec. 16).

Separation of Solids from Solids in Liquids

The resistance offered to the fall of particles through a liquid is used in several methods of separation of particles. Some of these methods depend principally on differences in particle size and others on differences in specific gravity. All these schemes were developed in the metallurgical industry where they are used to a much greater extent than in the chemical industry. The following arbitrary classification is offered for this equipment:

1. Basis of particle size.
   a. Settling basins.
   b. Classifiers.
   c. Elutriators.
2. Basis of specific gravity.
   a. Hydraulic jigs.
   b. Concentrating tables.
   c. Flotation machines.

Of these several methods, only the classifiers have been used to any considerable extent in the chemical industry, although the equipment of Group 2 is being used to an increasing extent in the concentration of nonmetallic materials for chemical processes.

Settling Basins.—Settling basins are used very little in the chemical industry for size separation. If particles suspended in water are carried into a region where the velocity is considerably decreased, the heavier particles will settle nearer the entrance, while the lighter particles will be carried nearer to the discharge. This method is employed today principally in equipment of conical shape known as Spitzkastens and Callow tanks. By employing a series of Spitzkastens of increasingly larger diameter, a fairly good size separation can be effected.

[1] Shepherd, C. B., and C. E. Lapple, *Ind. Eng. Chem.*, **31**, 972 (1939).

Classifiers.—Several sorts of classifier have been employed in the metallurgical industry, but only one of these has been used to any considerable extent in the chemical industry. This is the Dorr classifier, which is discussed by Anable (Perry's "Chemical Engineers' Handbook," Sec. 15). This equipment consists of a trough with a sloping bottom over which a reciprocating rake rakes settled solids from the feed end to the elevated discharge. Feed is at the deep end of the trough, at which end the fine materials which remain in suspension discharge with the water. The solids which settle are raked to the upper end and there discharged. A form of classifier for finer separations employs a small bowl thickener in series with the trough classifier. The fines discharge at the periphery of the bowl, and the oversize is raked out of the classifier.

The most important use of classifiers is in closed circuit with grinding apparatus. Classifiers also are used for the countercurrent washing of many materials and for the desliming of certain pulps. Table 48 shows the data required by the manufacturer in specifying a Dorr classifier.

A new classifier recently developed by the Hardinge Company also finds application in the chemical industry. This type of classifier consists of a sloping cylinder containing a spiral flight, which, when the cylinder rotates, tends to convey all material which settles to the central discharge. Fines overflow with the water from the lower end.

Elutriators.—These are of no commercial significance in the chemical industry, being used particularly in the metallurgical industry; they are sometimes employed in the laboratory for size determination. (Donaldson in Perry's "Chemical Engineers' Handbook," Sec. 15.)

Hydraulic Jigs and Other Concentrators.—*Jigs* are used to a considerable extent in the metallurgical industry in the concentration of ores, *i.e.*, in increasing the percentage of values in one fraction of a crushed material and decreasing it in the tailings. The crushed material is placed upon a screen and water is caused to flow up and down through it with a pulsating action. The particles of different specific gravities tend to segregate and stratify. However, the jigging action is also influenced by particle size and so tends to give only partial separation. A similar characteristic is inherent in the *concentrating table,* which

consists of a slightly sloping deck on the surface of which are riffles and which is given a reciprocating motion. The two foregoing methods have decreased relatively in importance, while

TABLE 48.—DATA SHEET

Inquiry should be accompanied by complete information, as outlined below, to enable us to determine the proper size of and specifications for classifier, and to plan a suitable closed-circuit arrangement where used.

Tons of dry solids per hour in original feed to classifier..............................
Tons of dry solids per hour in overflow (same as original feed for closed-circuit grinding)..............................
Specific gravity of solids..............................
Specific gravity of solution..............................
Mesh at which separation is desired..............................
Representative screen sizing of feed, if available..............................
Dilution of feed (ratio liquid to solid by weight)..............................
Limits of variation of feed dilution..............................
Dilution of overflow desired..............................
Permissible variation in dilution of overflow based on subsequent treatment..............................
General description of solids (mineralogical and physical)..............................
Approximate flow sheet immediately preceding and following classifier...
Position of drive pulleys (see sketch on page ——)..............................
Position of feed entrance (see sketch on page ——)..............................

Include following information if duplicating classification now being obtained in your plant, otherwise above information will determine these specifications.

Type of classifier..............................
Width and length..............................
Slope of bottom in inches per foot..............................
Speed of rakes (*i.e.*, R.p.m. of cam shaft)..............................

If for closed-circuit operation with grinding mill include following:

Make and size of mill..............................
Radius of feed scoop..............................
Diameter of discharge bell..............................
Overall length from outside feed scoop to outside-discharge bell..............................
Outside-diameter driving gear on mill..............................
Include certified general dimension drawing of mill if possible.

Side of mill on which classifier is to be placed (right or left hand when at end facing feed end of mill).

Where space is limited give the approximate dimensions that can be used.

When a new mill is to be purchased, it is advisable to delay specifying the radius of the feed scoop until the closed-circuit arrangement has been decided upon, and the most desirable radius of feed scoop determined.

flotation has increased in use with the discovery of new flotation agents. The basis of this operation is the fact that certain materials, such as pine oil, will attach themselves selectively to particles of certain chemical compositions. Thus, if the ore is ground finely and then mixed in water with the flotation agent at the same time that air is beaten into the mixture, bubbles of flotation agent and air will attach themselves to the valuable particles, causing them to float to the surface from which they can be skimmed. The gangue materials, however, sink to the

bottom and are drawn off. These three methods have been covered by Donaldson (Perry's "Chemical Engineers' Handbook," Sec. 15).

Separation of Solids from Liquids

A wide variety of equipment is employed for the separation of solids from liquids. In general, however, there are four principal divisions of this field as indicated in the following classification:

A. Pressing.
  1. Expellers.
  2. Curb presses.

B. Draining.
  1. Natural draining.
  2. Drag conveyors.
  3. Classifiers.

C. Filtration.
  1. Gravity.
    a. Sand filters.
    b. Bags.
    c. Nutsches.
  2. Vacuum.
    a. Intermittent.
    b. Continuous.
  3. Pressure.
    a. Plate filter presses.
    b. Leaf pressure filters.

C. Filtration (*continued*).
  4. Centrifugal.
    a. Batch.
    b. Semicontinuous.
    c. Continuous.

D. Settling and decanting.
  1. Thickeners.
    a. Nonmechanical.
    b. Mechanical.
  2. Centrifugals.
    a. Batch.
    b. Semicontinuous.
    c. Continuous.
  3. Liquid separators.
    a. Swing pipe.
    b. Multiple drawoff.

Pressing.—Mechanical and hydraulic presses are used for extracting oil from seeds, whey from casein, red oil from stearic acid, juices from fruits, etc. Depending on whether pressure is applied by a screw or by a mechanically or hydraulically operated plunger, this equipment takes the name expeller or press.

Draining.—Any operation in which liquid is removed from solids by the action of gravity while the solid is retained on the ground, on a sloping solid deck or on a screen is known as draining. The operation of the Dorr classifier depends in part on this phenomenon. Draining is also used for the partial dehydration of coarse solids which may be piled on the floor or supported on screens. (See Anable, Perry's "Chemical Engineers' Handbook," Sec. 15.)

Filtration.[1]—Since filtration is one of the most commonly used operations, both in chemical plants and in metallurgy, a great variety of filters has been developed. (See Irwin, Perry's "Chemical Engineers' Handbook," Sec. 15.) Filtration is the operation of separating a solid from a liquid by means of some form of membrane, usually a wire or fabric filter cloth. The membrane retains the solid, while the liquid passes through under whatever pressure is being used to effect the filtration.

Gravity Filtration.—The simplest of all filters, that in which the liquid is caused to flow through the filtering medium under the action of gravity, has several representatives, including the slow sand filter, ordinary filter bags and various sorts of false-bottom filters and nutsches. The latter is ordinarily a wooden filter tub, containing a perforated false bottom on which the filter membrane, usually a cloth, is supported. Vacuum may be applied beneath the cloth in this type, making it a vacuum filter. Such apparatus is used only when the resistance to filtration is relatively small; the equipment is generally homemade.

Vacuum Filtration.—Batch vacuum filters are of little importance today, although occasionally leaf-shaped elements, covered with filter cloth, are arranged for attachment to a source of vacuum and for lowering, by crane or other means, into a tank containing material to be filtered. Much more important than the batch type is the continuous type which has three principal representatives:

1. Drum type vacuum filters in which the filter membrane covers the outer periphery of the drum.
2. Drum type filters in which the filter membrane covers the inner periphery of the drum.
3. Vacuum filters with disk- or spindle-shaped filter elements.

With any sort of vacuum filter, the filtering pressure is less than 14.7 lb. per square inch. Consequently, this method is suited only to free-filtering materials, which will rapidly build a thin, unbroken cake on the filter surface. Filters of this type require little labor and have the advantage over pressure filters of giving a continuous discharge. Furthermore, in certain types, the cake can be more or less completely dried after wash-

[1] Wright, A., "Industrial Filtration," Reinhold Publishing Corporation, New York, 1923.

ing, by permitting warm air to be sucked through the cake before discharge.

Exterior Drum Filters.—This type, of which the Oliver is typical, is made in numerous sizes, up to diameters as large as 14 ft. or more. The periphery of the drum is divided into sectors, each of which is completely covered with filter fabric and independently connected to a port valve designed to control the application of vacuum and the efflux of filtrate, wash water and drying air. The drum is supported in a filter tank containing the material to be filtered. As it rotates, filtrate passes through the fabric and solids attach themselves to the surface. As rotation continues, the cake is usually sprayed with wash water and then scraped off just before it would return to the liquor tank.

Internal Drum Vacuum Filters.—This filter, of which the Dorrco is the representative, is similar in principle to the foregoing except that the filter fabric is applied to the inner surface of the drum so that the drum itself serves as the filter tank, thus adapting the machine to quick-settling solids. The discharge is accomplished from within the drum by means of a chute or screw conveyor.

Disk Vacuum Filters.—Such filters are known as the American type and are composed of from 1 to 12 disks, each of which is divided into several sectors which are individually connected to the proper discharge ports by means of a port valve. Filters with disks as large as 12 ft. in diameter have been built.

Spindle-type Vacuum Filters.—Vacuum filters with tubular elements are of two sorts, the filter type and the thickener type. The filter type uses tubular elements mounted on a spider which rotates in a manner similar to the drum of a continuous rotary filter, except that agitation of the tank contents is provided by a reciprocating motion superimposed on the rotation. The thickener type employs an intermittent reverse flow of filtrate to discharge the cake into the filter tank, so that the thickened cake settles to the bottom from which it can be withdrawn as a heavy sludge.

Table 49 is typical of the data sheets issued by vacuum-filter manufacturers to prospective purchasers.

Pressure Filters.—The principle of pressure filters differs from that of vacuum filters only in the fact that a positive rather than a negative pressure is used to force the filtrate through the filter

membrane. On this account, pressures as high as desired can be attained. Consequently, materials not filterable on vacuum filters may be handled by this means.

Filter Presses.—Filter presses are of two general types, those employing both plates and frames and those using recessed plates. In either case, two end supports, one of which is movable, are joined together by heavy side rails on which the plates and frames rest. The plates are grooved and serve as a backing for the filter cloth on which the solids are deposited, while the liquid passes through, runs out the grooves and leaves the press. In the case of the plate-and-frame type, the space for cake is supplied by the frames. In the recessed type, the recess in the plate accomplishes the same purpose. Filter presses are widely used

TABLE 49.—DORRCO FILTER INFORMATION SHEET

The following information should accompany requests for filter recommendations and quotations.

Number of filters wanted..........
Kind of material to be filtered..........
Maximum size of feed (mesh).......... %–200 mesh..........
Ratio liquid to solid in feed.......... Tons solids in feed per hr..........
or gallons per minute of feed..........
Specific gravity of solids.......... of liquid..........
Physical characteristics of solids (granular or clayey)..........
Chemical composition of liquid (if other than water)..........
Is cake to be washed.......... with..........
Soluble constituent to be removed.......... % in feed liquor..........
Per cent wanted in washed dry cake..........
State any limitation on amount of wash liquid..........
....
Is wash liquid to be kept separate from original liquid..........
Temperature of feed.......... of wash liquid..........
Elevation of plant above sea level..........
Direct connected motor or belt drives wanted..........
Electrical characteristics, A.C. or D.C.......... volts.......... cycles.......... phase..........
Should suitable vacuum pump and blower be included..........
If not, explain available vacuum and air pressure and volume available..........
....
....
Elevation of filtrate pump discharge above filter..........
Give any information available on filter results on same material..........
....
....
....
If liquid is corrosive state metals which will best withstand action..........
....
Name of Company..........
Name of Individual..........
Position..........
Mail Address..........
Shipping Address..........

and are available in numerous sizes. Table 50 gives a data sheet for information required in specifying filter presses.

Leaf Pressure Filters.—Such filters are of several types, but the principal variations are two: (1) filters containing stationary leaves; (2) filters containing rotating leaves. The latter type gives better uniformity of cake but is more expensive.

The first type is exemplified by the standard Sweetland filter and the Kelly filter. The former uses pancake-shaped filter elements covered with filter cloth and supported within a cylindrical casing, the bottom half of which drops for discharging. The Kelly press uses rectangular elements, disposed horizontally within a cylindrical casing which may be withdrawn over the

TABLE 50.—DATA SHEET

Fill out and return to

T. SHRIVER & CO.

Harrison, N. J.

1. Name of manufacturer........................Engineer........................
2. Address of manufacturer........................
3. Material to be filtered........................
4. Name and nature of liquid........................Sp. gr........................
   Acid, alkaline or neutral........................Viscosity........................
   Percent and kind of acid........................Alkali........................
5. Name and nature of solids........................Sp. gr........................
   Colloidal, fine, coarse, slimy, granular or crystalline........................
6. Ratio of solids to total by weight........................By volume........................
   Is ratio constant........................
7. Must cake be washed........................With what........................
   How thoroughly........................Maximum quantity of wash allowed........................
8. Do you save cake, filtrate and wash........................
9. May cake be air dried........................Is cake dried after filtration........................
10. Temperature of filtration. Minimum..........°C. Maximum..........°C.
11. Quantity of material to be handled per day of..........hours........................
12. What materials may be used for filtration equipment........................
13. How do you filter at present........................
    Filtering medium........................Pressure........................Filter aid........................
    Type of equipment........................
    Size........................Filtering area........................
    Capacity........................
14. What limitations must we observe in making recommendations in respect to present plant cycle........................
    ....
    Floor space........................
    General........................
15. Remarks........................
    ....
    ....
    ....

We require a minimum of five gallons of material for test purposes. Ship to

T. SHRIVER & COMPANY

Harrison, N. J.

via express or freight, Erie or Pennsylvania R.R. delivery.

TABLE 51.—DATA SHEET

UNITED FILTERS CORPORATION

Hazleton, Pa.

This sheet returned properly filled in will save time of preliminary correspondence and greatly facilitate a thorough understanding of your particular filtration problem. As much as practicable, of the information requested should be furnished us regardless of whether or not sample is submitted for tests.

We can serve you best by testing sample in our own laboratory. Ten to fifty gallons, depending upon the amount of solids in suspension, is sufficient. Forward sample to our Laboratory in Hazleton, Pa., by *express prepaid* and we shall make tests without any charge to you. Arrangements can be made to conduct tests in presence of your representatives if you so desire.

Please give us the names and addresses of your operators who may be interested.

Name of Company.. ....193.....
Manager... Engineer..
Post Office Address..
Freight Address..
Chemical composition or nature and density of liquid......................................
Chemical composition or nature and specific gravity of solids..........................
Relative proportions by weight of solids to liquids...
Which is the valuable product, liquid or solids or both?..................................
Physical characteristics of solids; *i.e.*, crystalline, granular, slimy, colloidal, etc..
Screen analysis

Retained on mesh	40	80	100	150	200	Through 200
Per cents...............................	%	%	%	%	%	%

Is it necessary to wash cake?....................How thoroughly?...............................
Must wash water be kept separate from filtrate?..
Temperature at which you prefer to filter................Permissible range.............
If liquid is acid, state kind and concentration..
If liquid is alkaline or caustic, state nature and percentage..............................
What metal, alloy or other materials best resist action of the material?........
....
Is it necessary to dry cake?...........................How thoroughly?..........................
Does cake crack on washing?...........................On drying?.................................
Must material be handled in batches?...
Will it be permissible to add a filter aid to increase filtering rate?.................
Elevation of installation above sea level...
Total quantity of solids (dry weight) or filtrate it is desired to handle per 24 hours. Also number of hours per day filter can be operated.................
Type, dimensions, area and capacities of present filter equipment.................
Remarks:..
....

ends of the elements for discharging. The rotating-leaf type is exemplified by the Vallez filter which uses either pancake type elements or radial leaves rotating within a cylindrical casing.

Table 51 shows the sort of data requested by pressure-filter manufacturers from prospective purchasers.

Filter Cloths.—Success in filtering depends largely on the suitability of the membrane chosen for the separation in question. Filter cloths are of numerous materials including cotton, nitrated cotton, wool, camel's hair, and numerous metals and alloys. No general-purpose filter cloth, suitable for all materials, has ever been developed.[1] To assist the filtration, it is often necessary to add a filter aid to the sludge before passing it into the filter. Filter aids are generally composed of diatomaceous earths, which are inert toward most of the substances filtered. They assist materially in clarification by depositing on the cloth and presenting a much less pervious filter surface. Filter aids are particularly useful for the removal of very finely divided materials.

Settling and Decanting.—Thickeners and settling tanks are most commonly thought of in this connection. However, immiscible liquids of different specific gravities are often separated by this means, as are liquids from liquids, and liquids from solids, by means of centrifugals.

Thickeners.—The simplest form of thickener is an ordinary settling tank arranged for the decantation of the clear liquid after settling. Nonmechanical, continuous settling tanks have conical bottoms from which thickened slurries high in solids, are continuously discharged. The most widely used thickener is the mechanical type of which the Dorr is typical. This is a square or circular settling tank, with discharge generally taking place from the entire periphery and with the feed at the center. Settled solids are moved to the bottom center by a rotating rake and discharged.

Centrifugal Separators.—A centrifugal separator consists of a rotating bowl or basket into which the materials to be separated are fed. The centrifugal force of rotation accomplishes the separation. Such separators are of several types, although there are only two fundamentally different principles employed. One sort, operating by filtration, uses a perforated basket on which the solids are retained while the liquid passes through. The

[1] New Aids to Filtration, *Chem. Met. Eng.*, **46**, 212 (1939).

other uses a solid basket or bowl against which the solids deposit, while the liquid remains closer to the center and is withdrawn over a dam. This latter type operates by accelerated settling and decantation and is also used for the separation of immiscible liquids. Small-diameter, high-speed machines, which are of the latter type, are generally known as *centrifuges*. Large-diameter, slower speed machines, which may be of either type, are generally known as *centrifugals*.[1]

Slow-speed Centrifugals.—This type is most generally built with a perforated basket which may or may not be lined with a filter fabric. In this type, the principal variations relate to the method of driving, one form being the underdriven (not much used in chemical industries) and the other form being the overdriven or suspended basket. For some materials, an open-bottom basket suffices to discharge the material automatically

TABLE 52.—CAPACITIES AND PERFORMANCE OF CONTINUOUS CENTRIFUGALS[1]

Basket diameter, in.	Maximum r.p.m. of basket	Low differential per 1,000 r.p.m. of basket	Capacity, tons per hour	High differential per 1,000 r.p.m. of basket	Capacity, tons per hour	Weight, lb.	Floor space, sq. ft.	Horse power
48	1,000	8	25	60	100	12,000	49	30
36	1,200	8	15	60	60	9,000	49	25
26	1,600	6	6	40	30	5,500	25	15
18	2,100	4	½	30	4	4,000	20	10

[1] C. H. Elmore.

when the speed is slackened sufficiently. In others, material must be dug from the basket and discharged from the bottom, when the bottom valve plate is opened. Automatic diggers are available. One form of centrifugal employs a basket rotating on a horizontal axis and is capable of discharging at full speed and so gives semicontinuous operation. Another form of continuous centrifuge (Bird) utilizes the conical horizontal revolving chamber, throwing the solids against the inner face of the cone, from which it is scraped and moved forward to the small discharge end, while the liquid, confined to the larger end of the cone, flows out at that end. Other types, built both with horizontal

[1] SHARPLES, L. P., *Ind. Chem. Eng.*, **31**, 1072 (1939).

TABLE 53.—CAPACITIES OF BATCH CENTRIFUGALS[1]

Type of centrifugal	Suspended						Center slung					Solid curb				
Inside diam. of basket, inches	12	20	26	32	40	48	40	48	54	60	72	12	16	20	26	30
Normal r.p.m. of basket	1,725	1,725	1,160	1,150	850	720	850	750	650	550	450	2,200	1,800	1,400	1,050	950
Capacity in cu. ft.:																
Total	0.31	2.22	5.2	9.4	17.5	25.7	12.3	19.1	26.5	32.4	46.8	0.42	0.76	1.53	3.4	5.0
Under top ring	0.17	0.97	2.4	5.5	8.6	12.8	6.4	10.0	12.5	16.4	23.6	0.17	0.23	0.59	1.7	2.8
Gallons:																
Total	2.32	16.6	39	70	131	192	92	143	198	242	350	3.15	5.7	11.5	25.4	37
Under top ring	1.27	7.25	18	41	64	96	51	75	93	122	176	1.27	1.72	4.4	12.7	21
Centrifugal force at normal speed	508	846	498	603	412	354	412	384	324	258	208	826	677	446	408	385

[1] Tolhurst Machine Works, Inc., October, 1934.

and with vertical baskets, are equipped with scraping devices within the basket which continuously remove the solids and thus give continuous performance. Table 52 shows capacities and performance of Elmore continuous centrifugals. Table 53 gives capacities of various types of Tolhurst batch centrifugals.

One form of slow-speed centrifugal employs a solid basket for the accelerated settling and intermittent discharge of solids. This type is generally used for clarification, *i.e.*, where the percentage of solids is low. Continuous centrifugals of the slow-speed type are also built with solid baskets.

High-speed Centrifuges.—These are of two types: the Sharples type which employs a long hollow bowl of small diameter and is rotated at a very high speed; and the DeLaval type, employing a short disk bowl of large diameter. Such equipment is used largely for clarification and for separation of immiscible liquids.

A variation of the high-speed type, for intermittent but semi-automatic discharge of the solids, is the Rotojector which uses hydraulic pressure generated by the rotation of the bowl to uncover ports for occasional discharge of the solids.

A convenient means of estimating the effect of centrifugal force is to compare that force with gravity which may be done by the following approximate formula:

$$\frac{DS^2}{5{,}000} \quad N$$

where D = diameter of basket in feet.
S = r.p.m. of the basket.
N = the number of times centrifugal force exceeds gravity.

Separation of Liquids from Liquids

Liquids which are immiscible and not emulsified one within the other are readily separated by gravity settling and decantation. This separation may be hastened by the use of centrifugal separators which, under certain circumstances, are also able to effect the separation of emulsions.

MIXING

Whether the materials mixed are liquids, solids or gases, or any combination of these, the fundamental object to be accomplished by theoretically perfect mixing is always the same and has been

defined by Valentine and MacLean (Perry's "Chemical Engineers' Handbook," Sec. 14) as follows: "In all cases two or more materials existing either separately or in an unevenly mixed condition are, by mixing, to be put into such a condition that each particle of any one material lies as nearly adjacent as possible to a particle of each of the other materials." Such perfect results are never attained in practice, and, in fact, there are cases where this perfection would not be desirable. However, the object in most cases is to approach as closely as possible to the ideal with the minimum expenditure of power and in the shortest, most economical period of time.

Mixing, to a greater extent than any other of the chemical unit operations, retains its status as an art, for it still has very little scientific foundation. On this account, a great number of types of mixer have been developed, many of which are far from satisfactory. Furthermore, each industry has developed its own particular form of mixer, whereas it is probable that, with a better scientific basis, a comparatively smaller number of types would serve for all industries.

Valentine and MacLean have stated that the practical aims of mixing are four:

1. To produce simple physical mixtures, such as that of two or more miscible fluids, two or more uniformly divided solids, or a mixture of phases where no reaction or changes of particle size take place.
2. To accomplish physical change, such as the solution of one component in another, the formation of crystals from a supersaturated solution, the selective adsorption of minor constituents by adsorbents such as fuller's earth, and the flocculation or deflocculation of particles.
3. To accomplish dispersion, wherein a quasi-homogeneous product is produced from two or more immiscible fluids, or one or more fluids with finely divided solids.
4. To promote a reaction. This latter is perhaps the most important use of mixing in the chemical industries, since intimacy of contact between reacting particles is necessary as a condition of proper reaction.

The choice of a suitable mixer will often depend upon trial, although certain types are known to be suitable for particular sorts of mixing problems. One fact, however, may generally be definitely stated, and this is that the proper performance of a mixing operation can usually be obtained only in a machine of a calculated size, or smaller. This follows from the fact that the mixer size increases in three dimensions, whereas the active

surface of contact increases in only two dimensions. On this account it will often be necessary to duplicate a suitable small machine to provide given capacity, rather than to employ a single larger machine.

Badger and McCabe[1] have stated that the simplest classification of mixing problems includes three types: (1) mixing of liquids with liquids; (2) mixing of liquids with solids; (3) mixing of solids with solids. A somewhat more complete classification is that of Valentine and MacLean who have divided some forty types of mixers into the following:

1. Flow mixers.
2. Paddle or arm mixers.
3. Propeller or helical mixers, including screw conveyors.
4. Turbines or centrifugal impeller mixers.
5. Miscellaneous types including slurry, mass, solid and drum mixers.

It will be noted that this second classification is based upon equipment rather than materials.

The requirements of a satisfactory mixer, according to Valentine and MacLean, are first, that it yield a desired degree of mixing at the point of most intense agitation; and second, that a satisfactory rate and direction of motion of the entire body of material, however remote from the mixing element, must be established and maintained. Whether a particular type of mixer will meet these criteria in a given problem can often be determined only by experiment. Specific performance will be influenced by the following physical factors which play a part in all mixing operations:

1. Consistency or apparent viscosity of the mixture, and mixing velocity.
2. Specific gravity of the continuous phase, and relative gravities of each phase.
3. Other physical properties of the material, before or during mixing.
4. Relative proportion of the materials and their order of addition to the mixture.

Flow Mixers.—In mixers of this type, the material is practically always pumped through, and the mixing effect produced by interference with the flow. Mixers of this type are used in continuous or circulating systems, generally for miscible fluids, or occasionally for the mixing of two phases. This principle of

[1] BADGER, W. L., and W. L. McCABE, "Elements of Chemical Engineering," 2d ed., p. 511, McGraw-Hill Book Company, Inc., New York, 1936.

mixing is employed in mixers where one jet impinges upon another, in injector mixers where a second ingredient is injected into the main stream, in baffle and orifice columns, in air-lift and long draft-tube mixers, in mixers using centrifugal pumps with or without recirculation, and in towers for the absorption of gas in liquids.

Paddle or Arm Mixers.—This group includes a great number of types ranging from simple paddles to combinations of stationary and movable paddles, and double-motion agitators consisting of two paddles operating in opposite directions. This group includes the familiar horseshoe type of agitator suitable for mixers where the material must be scraped continuously from the sides of the containing vessel. It includes traveling paddle agitators used in large tanks containing slurries upward of 1,000 cu. ft. capacity which must be kept in suspension by agitating at a rate of 1.5 to 6.5 r.p.m. such as mixed raw materials for Portland cement manufacture. It also includes a number of more specialized mixers such as those in which a group of paddles is set off center, with or without the addition of one or more mulling wheels, within a rotating pan; and those in which a rotating paddle set off center describes an epicyclic course in a stationary pan. The group also includes heavy double-arm dough mixers with impellers of the Z or S type for the handling of heavy, doughy, gummy and plastic masses.

Propeller Mixers.—Propellers of three or four blades, operating with peripheral speeds in the range between 1,000 and 2,000 ft. per minute, are often used for mixing operations. The portable types, generally using two propellers with blades set to propel in opposite directions (push-and-pull type), are most common. Sometimes, however, a permanent installation is made with the propeller driven from the top or through the side of the tank. One of the most efficient types employs a draft tube consisting of a concentric tube surrounding the propeller, usually with close clearance, and so set as to guide the flow and give the greatest possible motion to the entire tank contents. A variation of this type is the soap crutcher, which substitutes a continuous helix for the propeller and is suitable for the mixing of heavy pastes. Another form of helical mixer is the horizontal, double-ribboned type, in which scraping and mixing flights, supported on a rotating shaft within a horizontal trough, are used to accomplish

the mixing of solids. This type is occasionally used for moderately thin pastes as well.

Turbine Mixers.—Turbine mixers use impellers similar to a centrifugal pump impeller, submerged in the material to be mixed and rotating at moderately high velocity. The impeller may or may not be provided with stationary deflecting rings. The most efficient type, however, employs such a deflector and thus makes possible the most efficient application of power. In this type, motion is largely in a radial direction until the flow strikes the container wall, whereupon it travels upward or downward and returns to the impeller, thus bringing the entire contents of the container under the mixing influence. One patented form of the turbine mixer, the Turbo-mixer, is made in a number of variations for both batch and continuous mixing of liquids, with viscosities as high as paints and lower, and for the contacting of liquids and gases.

Miscellaneous Mixers.—The tumbling barrel, ball mill, rake mixer, spray type Feld scrubber, paper beater, mixing or compounding roll and putty chaser are among the miscellaneous types of mixing equipment. Compounding of heavy, semidry masses such as required for Haveg construction has led to the introduction of the Lancaster type pan mill, which has a revolving pan as well as a circular motion of the muller. In addition may be mentioned the colloid mill and the homogenizer. There is some overlap between the fields of these two machines, but, in general, it may be stated that colloid mills are mostly used for the dispersion of liquids and solids, whereas homogenizers are used entirely for the production of emulsions. A secondary application of the colloid mill is for this latter purpose.

Colloid Mills.—The action of colloid mills is a combination of fluid shear and (usually) impact caused by high centrifugal force. Although there are many different types of construction, all colloid mills operate by forcing the materials to be dispersed or emulsified between surfaces placed very close together and having a high relative velocity with respect to each other. In some colloid mills this relative velocity is obtained by the use of two closely placed rotors, rotating in opposite directions. In others, a rotor rotates with close clearance within or adjacent to a stator. Colloid mills have very high power requirements, the commercial units varying from 5 to 100 hp. at 3,600 r.p.m.

Homogenizers.—The homogenizer consists of a high-pressure hydraulic pump in combination with a spring-loaded valve through which the pressure is suddenly released so as to give a very high degree of impact of the components being emulsified against a plate or ring. Pressures in excess of 1,000 lb. per square inch are generally employed. Homogenizers are used in the production of certain pharmaceuticals and cosmetics, and to a considerable extent in the dairy and ice-cream industries.

Power Consumption of Mixers.—Not much information on the power consumption of mixing equipment is available. Badger and McCabe (*ibid.*, pp. 514–516) give power-r.p.m.-time

TABLE 54.—KOVEN MIXER SPECIFICATION SHEET

It will help a great deal in making our recommendations if you will answer the following questions in as much detail as possible:

1. What are these mixers to be used for?..
   ....
   (*a*) If solids, give the size of particle and the kind of solvent used. Also give viscosity of the finished product.
   (*b*) Name common material nearest in consistency to the product which you will finally obtain, such as water, light oil, heavy oil, molasses, dough, etc.
2. Required capacity in gallons?..
3. Space available to set up mixer:—
   Width?...................... Height?..........................
4. What is the metal out of which mixer is to be made?..............................
5. Is mixer to be lined?...........................If so, with what material?............
6. Is mixer to be plain or jacketed?..
   (*a*) Full jacketed..............................Pounds pressure?...........................
   (*b*) Half jacketed.............................Pounds pressure?...........................
   (*c*) Bottom only jacketed...............Pounds pressure?...........................
   (*d*) Sides only jacketed...................Pounds pressure?...........................
7. Is mixer to be heated?..
   (*a*) Direct fired?.............................. ....
   (*b*) Indirect fired?............................At what pressure?..........................
   (*c*) Coil heated?..............................What is the size of coil?.................
   Of what metal is coil to be made?...................
8. What is to be the shape of head?
   (*a*) Flat.................Riveted, bolted, half-hinged, or full-hinged?...........
   (*b*) Concave..........Riveted, bolted, half-hinged, or full-hinged?...........
   (*c*) Convex............Riveted, bolted, half-hinged, or full-hinged?...........
   (*d*) Conical...........Riveted, bolted, half-hinged, or full-hinged?...........
   (*e*) Open...............
9. What is to be the shape of bottom?
   (*a*) Flat.............................. (*c*) Concave.......................
   (*b*) Conical...................... (*d*) Convex.........................
10. Inside Details: Is mixer to be
    (*a*) Open?.................Half-hinged?..................Full-hinged?...................
    (*b*) Pressure tight?.......................Pounds pressure?................................
    (*c*) Vacuum tight?.........................Inches of vacuum?...............................
    (*d*) Vapor tight?..............................
11. Type of stirrer. Send sketch if possible, or refer to illustration in booklet that nearest fits your needs.
12. Send sketch showing location with sizes clearly marked of all tappings.

characteristics for paddle stirrers. Valentine and MacLean give theoretical horsepower requirements for propellers. The latter state that the power consumption of colloid mills and homogenizers, for production of 100 gal. per hour, will vary between 20 and 50 hp. These authors also give figures on power consumption for occasional specific problems.

Choice of Mixers.—As has been indicated, mixer choice frequently is a matter of experience or experiment. Consequently, the tabular matter of Valentine and MacLean in which specific recommendations for certain mixing ranges are made, should be of great value.

Materials of Construction.—Practically any material of construction may be used in a mixer. Wood and mild steel are the most common materials, but almost all of the special metals and alloys, as well as nonmetallic coatings, can be used (see Tables 41 and 42).

A sample specification sheet for the determination of suitable mixer types is given in Table 54.

Process Mixing Equipment.—A great number of specific pieces of process equipment incorporate mixers of one sort or another, usually for the promotion of reaction. Among these pieces of equipment may be mentioned autoclaves, bleaching equipment, cookers, chlorinators, digesters, dissolvers, emulsifiers, extractors, kettles, nitrators, percolators, retorts, reducers and sulfonators.

EVAPORATION

Evaporation may be defined as the removal of solvent from a solution by vaporization, with the production of a concentrated solution containing a higher proportion of the solute and a lower proportion of the solvent. As distinguished from distillation, in which two or more components of the solution are capable of vaporization, evaporation refers to vaporization separations where one component is generally a solid and the other a liquid, generally water.

In the majority of evaporation problems, the product is, as stated, a concentrated solution from which the solids may be recovered by crystallization or subsequent drying. Drying, therefore, is usually taken to cover those evaporation problems in which the solid component is recovered in a dry or substantially dry state.

Classification of Evaporators.—According to Badger (Perry's "Chemical Engineers' Handbook," Sec. 8) evaporators are best classified as follows:

A. Apparatus using solar heat.
B. Apparatus heated by direct fire.
C. Apparatus with heating medium in jackets, double walls, etc.
D. Steam-heated evaporators with tubular heating surfaces.
  1. Tubes horizontal.
    a. Steam inside tubes.
    b. Steam outside tubes.
  2. Tubes vertical.
    a. Standard (calandria) type.
    b. Basket type.
    c. Long-tube type.
    d. Forced-circulation type.
  3. Tubes inclined.
  4. Specially shaped tubes.

Evaporator Operation.—Most evaporation in chemical industry is carried out under vacuum (1) in order to avoid injury to delicate substances by the reduction of boiling temperature, and (2) for increased economy through the utilization of multiple-effect evaporation. Any evaporator body in which a condensing vapor may be used as the heating medium, and which may be put under vacuum, may be operated in multiple effect with other evaporators of a similar sort. By this method of operation, the first evaporator, generally using steam as the heating medium, boils off vapor which is condensed in the heating jacket or tubes of the second effect. Similarly, vapor boiled from the second effect is used as the heating medium in the third effect, and so on, for perhaps as many as six effects. In any event, the vapor from the last effect will be condensed in a condenser. The result of using each succeeding effect as a condenser for the preceding, is to put each later effect under higher vacuum and lower boiling temperature. Noncondensable gases evolved in each effect must be withdrawn, together with condensate, by a vacuum pump. The economy from the use of multiple effect arises from the fact that the same number of pounds of steam required to evaporate 1 lb. of water in the first effect will evaporate roughly 1 lb. in the second effect, 1 lb. in the third, etc. Thus, if 1 lb. of steam will evaporate 0.8 to 0.9 lb. of water in the first effect, it will evaporate, say, 0.85 N lb. in an evaporator of N effects.

Where a great quantity of evaporation of a low-cost product must be accomplished, it is generally economical to use a large number of effects, for example, as many as five or six. The proper number to use can only be determined by calculations showing which number will have the smallest combined total of operating and fixed charges.[1]

However, in certain industries, multiple-effect evaporation cannot be used as an economy measure because of the comparatively high temperature maintained in the first effect. In the case of delicate materials such as concentrated milk products, fruit juices and pharmaceuticals, it is often necessary to use single-effect vacuum evaporators, and accept high operation cost in order to preserve the quality of the product.

Direct-fired Evaporators.—Small water stills, caustic dehydration pots and, of course, steam boilers are the principal representatives of this group.

Jacketed Apparatus.—Much small-scale evaporation is accomplished in jacketed kettles and similar apparatus. Such evaporation is generally atmospheric, although, if the kettle construction is suitable, it may be carried out under vacuum.

Horizontal-tube Evaporators.—Horizontal-tube evaporators are of two general types, those with the steam inside the tubes and those with the steam outside. The first type ordinarily consists of a vertical body of cylindrical shape with two steam chests on opposite sides, near the bottom, connected within the evaporator body by a considerable number of horizontal tubes. This type is best suited for nonscaling, noncrystallizing and nonviscous solutions. Evaporators of the second type, of which the only survivor is the Yaryan, consist of a horizontal casing containing a number of series of tubes, through which the solution moves at high velocity, discharging into a chamber containing baffles to separate the vapor from the concentrated solution. It is best suited for foamy liquids. The bodies of horizontal-tube evaporators vary between 5 and 10 ft. with tube lengths from 3 to 16 ft.

Vertical-tube Evaporators.—Standard and basket-type evaporators are essentially similar in that they employ a vertical cylindrical evaporator body of diameter less than the height, containing a number of vertical tubes with the steam outside. These

[1] Badger, W. L., *Trans. Am. Inst. Chem. Engrs.*, **13**, ii, 139 (1920).

are constructed in sizes with diameters from 6 to 24 ft. In the standard type, the steam space is formed by tube sheets which extend horizontally across the shell, space allowed for a central downtake. In the basket type, the heating element is a separate unit and the downtake is an annular ring between the shell and the heating element. The so-called *long-tube*[1] evaporator, of which the Kestner is representative, employs no evaporator shell proper. Rather, a group of long tubes contained within a cylinder closed at the ends by tube sheets, with steam around the tubes, discharges into a vapor drum placed above the tubes. Motion up the tubes is accomplished by the expansion of steam liberated from the solution. In the Kestner type, liquid passes through the tubes but once. In the Webre type, recirculation is possible. In the *forced-circulation type,* a shorter tube length and a larger vapor space above the tubes are employed, together with a centrifugal pump which recirculates and forces the liquid up through the tubes with a positive velocity.

Of these vertical-tube evaporators, the standard type is especially adapted for solutions that deposit scale or crystals. The application of the basket type is similar. The long-tube type is not suitable for scaling and salting liquids, while the forced-circulation type, by the addition of a salt separator, may treat salting liquors as well as clear liquors. This last type is especially adapted to the evaporation of viscous materials and liquors requiring expensive materials for the heating surface. Because of the high velocity, the coefficient to heat transfer is especially high in this type. Heating surfaces from 35 to 8,000 sq. ft. are available.

Inclined-tube Evaporators.—Evaporators in this group are similar in construction to the long-tube type except that, by reason of the slope of the tubes, these need not be so high. This type employs recirculation and, because of the high velocity attained, gives a high coefficient of heat transfer. Such evaporators are generally not suitable for salting and scaling liquids, although in some modifications ready removal of scale from the tubes is accomplished.

Special-tube Evaporators. Coiled tubes are employed in strike pans for crystallizing second and third sugars in sugar mills with capacities of 25 to 120 tons, varying from 8 to 18 ft. in

[1] Badger, W. L., *Chem. Met. Eng.*, **46**, 640 (1939).

TABLE 55.—DATA REQUIRED FOR SELECTION OF EVAPORATOR

1. Analysis of liquor; if not available send sample.
2. Quantity to be handled in the evaporator per day, per hour.
3. What will be the average initial density (specific gravity, Baumé, or Twaddell), and percentage of solids?
4. What is the initial temperature?
5. What final density or condition is desired?
6. Are there any marked effects or changes of properties produced by temperature changes?
7. What are the boiling points at atmospheric pressure of the dilute solution and of the same solution at the final state of concentration which you wish to reach?
8. State any peculiar properties such as tendency to foam, entrain, evolve gases, become viscous, deposit crystals, sludge, etc.
9. Are there any scale-forming ingredients, such as sulfate of lime, phosphate of lime, silica, etc.?
10. What steam is available for evaporation purposes, live or exhaust? Will it be necessary to install a boiler?
11. In what quantity is water available to operate a condenser? What is the source of the water and at what temperature can it be obtained? State quality of water.
12. Is your solution neutral, acid or alkaline in its reaction? Have you found that any particular metal or metals must be avoided in the construction of an evaporator, and what metals can be used?

diameter, and also in distilled-water evaporators. In the latter application, the design is such that temperature changes cause movement of the coils and thus serve to crack off scale.

Table 55 gives a summary of data required by manufacturers in the specification of suitable evaporators.

HEAT EXCHANGERS AND CONDENSERS

Although a condenser is, in fact, a heat exchanger, the term *heat exchanger* is generally reserved for concentric-tube apparatus or one consisting of tubes running between tube sheets and mounted within a shell. Heat exchangers transfer heat from a warmer material which it is desired to cool, to a cooler material which it is desired to warm. A *condenser*, on the other hand, makes use of a cooler material to remove the latent heat of vaporization from a vapor which it is desired to condense, either by direct contact or by indirect contact through tubes or plates. Heat exchangers are used for the cooling or heating of all sorts of process materials, while condensers are used largely for the condensation of vapors from evaporators and consequent production

of vacuum, and for the recovery of materials volatilized from stills.

Heat Exchangers.—Heat exchangers are built in a great number of designs, but three types are most common, including: (1) coils submerged in liquid; (2) tubular heat exchangers consisting of tubes supported within a shell by means of tube plates, one of which generally floats, to provide for expansion; and (3) double-pipe heat exchangers consisting of two concentric pipes, one for the warm fluid and one for the cool fluid. Data on heat transfer in heat exchangers are given by McAdams in Perry's "Chemical Engineers' Handbook," Sec. 7.

Condensers.—Many condensers are constructed along the lines of one of the heat exchangers mentioned above, principally types 1 and 2, in which case they are known as *surface condensers* and are used where it is necessary to avoid mixing the condensed vapor with the cooling liquid.[1] Condensers for use on evaporators are generally of the jet type, in which the cooling water mixes with and condenses the vapor. *Jet condensers* are of two types, one in which the flow of vapor and cooling water is parallel, and the other in which the flows are countercurrent. Jet condensers are generally provided with a barometric leg consisting of a tail pipe extending downward from the condenser body about 35 ft., and terminating beneath the surface of water in the "hot well," which serves as a barometric seal. By this means, water may be removed from the condenser at any vacuum possible with the existing cooling water temperature and without the use of a vacuum pump. However, it will generally be necessary to provide a small dry vacuum pump or steam jet for the removal of noncondensable vapors.

Still a fourth form of condenser is the *eductor* type, consisting of a venturi type jet compressor, in combination with a surface condenser. This type requires large volumes of cooling water but has the advantage of operating at a higher cooling-water temperature by reason of the compressor action of the jet, and operating without a vacuum pump.

Cooling Towers.—Since the operation of condensers depends upon adequate cooling water of sufficiently low temperature, economy sometimes requires the use of recirculation and of atmospheric evaporative cooling. For this purpose, either

[1] Colburn, A. P., and O. A. Hougen, *Ind. Eng. Chem.*, **26**, 1178 (1934).

spray ponds or cooling towers are employed. Spray ponds are rarely used except in large installations, whereas cooling towers have the advantage of ease of operation and relatively small size. In either case, advantage is taken of the evaporation of a

TABLE 56.—DATA REQUIRED FOR ESTIMATING CONDENSERS AND HEAT EXCHANGERS

Condensers

1. Quantity of vapor to be condensed, pounds per hour.
2. Pressure or degree of vacuum at which vapor enters condenser.
3. Quantity of cooling water available, and probable range of initial temperature.
4. Working pressure of cooling water, and allowable pressure loss in passing through tubes of condenser.
5. Chemical characteristics of cooling water.
6. Type of condenser desired: whether vertical or horizontal.

Heat exchangers

1. Quantity to be heated, pounds or gallons per hour.
2. Initial temperature.
3. Final temperature.
4. Steam pressure, pounds per square inch (specify whether gage or absolute).
5. Steam quality: superheat in degrees, or per cent of moisture.
6. Working pressure of water to be heated.
7. Allowable pressure loss through tubes of heater.
8. Type of heater: horizontal or vertical.
9. Space available, including allowance for tube removal.

small part of the water, in contact with the air, to cool the remainder. Cooling towers are of two types, natural draft and forced draft.[1] In either type, the water is distributed over a large surface, usually of wood grids, so as to facilitate evaporation.

Data Required.—Table 56 shows the type of information required by manufacturers for estimating heat exchangers and condensers. Table 57 gives a sample data sheet on cooling-tower requirements.

CRYSTALLIZATION

Crystallization involves, generally, the evaporation and subsequent cooling of a solution to the point of supersaturation, whereupon the formation of crystals takes place. Much of the work that has been done in the evolution of crystallization

[1] SIMMONS, E., *Chem. Met. Eng.*, **46**, 146 (1939).

apparatus has been pointed toward the control of crystal size, since trade demands frequently are rigorous in this regard.

McCabe (Perry's "Chemical Engineers' Handbook," pp. 1779–1798) has classified commercial crystallization apparatus and discussed engineering and cost data.

TABLE 57.—COOLING PLANT DATA SHEET

THE COOLING TOWER CO., INC.
15 John Street, New York City

Firm name__________Location of plant__________(City and State)
Is place selected for apparatus well exposed to prevailing summer winds?
Yes☐ No☐
Shall we quote on cooling tower☐ or spray pond?☐
Available space for cooling tower or spray pond.
Width________ft. Length________ft.
Is space on ground☐ or on building roof?☐ Please furnish building plan or make sketch on the reverse side of this sheet.
Is exterior woodwork prohibited by local authorities? Yes☐ No☐
Available supply of make up water. Well water☐ City water☐ Other source☐
Amount available________gals. per minute. Its average summer temperature________.
Purpose for which cooling water is to be used. Please fill in below.

Refrigeration
Rated capacity of machines in tons of refrigeration_____(not in tons of ice).
Compression☐ Absorption☐ Raw water☐ Distilled☐
Number of stands of ammonia condensers________Single tube________
Double tube________.
Number of pipes high________Diameter of pipe________in.
If distilled water plant give details of steam condenser.

Steam condensing
Type of engines or turbines________
________H. P.________K. W. Weight of steam per hour to be condensed________lbs.
Vacuum in inches of mercury required at 30″ barometer________in.
Surface type☐ Jet☐ Barometric☐ Maker________
Is condenser fitted with dry vacuum pump? Yes☐ No☐

Water jackets of internal-combustion engines and air compressors
Maker________Size________Rated Hp.________

Electric transformers
Circulation of water required in gallons per minute________gal.
Highest temperature of water allowable on transformer________
Off transformer________

Oil refineries, casing-head plants, aeration, gas scrubbing, etc.
Describe fully how water is to be used and give quantity of water and hot and cold water temperatures.

Crystallizing Evaporators.—Crystallization frequently takes place in evaporators, either as the main feature or as a subsidiary feature of the evaporation. In some cases, as in the evaporation of salt and in the recovery of salt and glycerin in soap manufacture, salt separators are provided to remove crystallized material as rapidly as it settles.

Batch Crystallizers.—Atmospheric cooling and crystallization in open tanks are practiced with certain materials today, although less commonly than was formerly the case. In such a case, the usual practice is to concentrate the solution to a point approaching saturation; then to cool the solution by natural convection in open, rectangular tanks, whereupon crystallization takes place, usually without any attempt to control crystal size. One of the most common crystallizers of this type consists of a cylindrical metal tank with conical bottom containing cooling coils and a propeller type agitator, usually installed within a draft tube. The agitation improves the heat transfer and keeps the fine crystals in suspension, giving them an opportunity to grow uniformly. Because there are many new nuclei formed in this type, the crystal size is much finer than that produced by unagitated methods.

Continuous Crystallizers.—The most common type of continuous crystallizer used in the United States is the *Swenson-Walker* which consists of a horizontal, open-top, jacketed trough containing a ribbon agitator. Several troughs are generally joined together to give lengths as great as 40 ft. Hot concentrated solution is fed to one end and flows through the trough, usually countercurrent to the cooling water. Crystals and mother liquor are removed together from the discharge end and separated on a draining table.

A crystallizer that has been used to a considerable extent in Europe is the *Wulff-Bock* which consists of a shallow, inclined trough set on rollers so that it can be rocked from side to side. This crystallizer has small capacity but can make larger crystals than the Swenson-Walker.

The *Jeremiassen*, or *Oslo*, crystallizer has recently been introduced into the United States. It is made in various forms for multiple-stage evaporation, evaporation with recompression of the vapor, vacuum cooling or cooling to low temperatures with cooling liquids. However, all these forms control crystal growth by causing the supersaturated solution, cooled to crystallization temperature, to pass upward through a perforated plate above which crystal nuclei are kept in suspension. Positive circulation is maintained by a centrifugal pump. Crystals are removed continuously by a salt elevator or some other suitable means.

The *Howard crystallizer* is a jacketed conical vessel somewhat similar to a double-cone classifier. Solution enters at the bottom and flows upward, meanwhile being cooled. Crystals are held in suspension until their sizes increase sufficiently so that they settle and are withdrawn from the apparatus.

Vacuum Crystallizers.—Vacuum crystallization, a comparatively recent development in the United States, will probably be used more extensively in the future. Such crystallizers operate in a manner similar to the steam-jet refrigerator for cooling water. A warm, saturated solution is conducted into a cylindrical body evacuated by means of a jet compressor and a condenser. On account of evaporation, the solution is cooled to the boiling temperature corresponding to the vacuum and, in so doing, permits the growth of crystals. The crystals and mother liquor settle through a barometric tail pipe and are then separated by draining. Vacuum crystallizers offer many advantages including that of having no moving parts. Since they have no heat-transfer surfaces, materials of construction may readily be employed which are poor heat conductors, such as rubber linings. Equipment of this type may be built in any desired capacity.

DRYING

According to Sherwood (Perry's "Chemical Engineers' Handbook," p. 1480) drying refers to the removal of a liquid, usually water, from a solid. There is no hard-and-fast distinction between drying and evaporation, except that the former usually concerns solids which are not in solution, whereas the latter deals with the concentration of solutions.[1] A further distinction, necessarily, is in the type of equipment employed.[2,3] Drying may be accomplished by various means, but the only one to be considered here is the means employing evaporation of the water. The mechanical forms of drying, including centrifuging, pressing, filtering and draining, are sometimes used in advance of thermal drying in order to reduce the moisture content and decrease drying costs.

In all types of dryers, some means must be provided for supplying the heat required to evaporate the moisture present, and for

[1] LISSAUER, A. W., *Chem. Met. Eng.*, **46**, 517 (1939).
[2] HOUGEN, O. A., *Chem. Met. Eng.*, **47**, 160 (1940).
[3] URE, S. G., *Chemistry & Industry*, **43**, 350 (1924).

removing the vapor. A rough classification may be based on the method of removing the moisture after evaporation, thus dividing dryers into two types: (1) dryers in which the moisture is swept away from the material by air or other gas;[1] and (2) dryers in which the moisture is removed by condensation in a separate condenser, with the material placed within a vacuum chamber. In the first type, heat is generally conveyed to the material by the same air which removes the moisture. On the other hand, occasionally the air may be supplied at atmospheric temperature and the drying accomplished simply by increasing its degree of saturation. In the second type, heat is generally supplied to the material indirectly by contact with heated (generally steam-heated) surfaces.

A more extensive classification of dryers[2] is based upon the type of material to be dried. This is logical, in view of the fact that dryer form is largely determined by material form:

A. Materials in sheets or masses carried through on conveyors or trays.
- 1. Batch dryers.
  - *a*. Atmospheric cabinet dryers.
  - *b*. Vacuum chamber and shelf dryers.
- 2. Continuous dryers.
  - *a*. Continuous conveyor and tray dryers.
  - *b*. Roll dryers.

B. Granular or loose materials.
- 1. Rotary dryers.
  - *a*. Atmospheric, direct heat, countercurrent.
  - *b*. Atmospheric, direct heat, parallel current.
  - *c*. Atmospheric, direct heat, two-pass.
  - *d*. Atmospheric, indirect-direct heating.
  - *e*. Vacuum rotary.

C. Paste and sludges or caking crystals.
- 1. Agitator dryers.
  - *a*. Atmospheric.
  - *b*. Vacuum.

D. Materials in solution.
- 1. Drum dryers.
  - *a*. Atmospheric.
  - *b*. Vacuum.
- 2. Spray dryers.
  - *a*. Air.
  - *b*. Superheated steam.

[1] Drying of Air, *Chem. Met. Eng.*, **47**, 228 (1940).

[2] Cronshaw, H. B., "Modern Drying Machinery," Ernest Benn, Ltd., London, 1926.

For the drying of materials in sheets or masses, dryers capable of supporting the material in the desired atmosphere for an adequate period of time are necessary. In batch dryers, material is held in place and subjected to the desired conditions or cycle of conditions. In continuous dryers, the material is conveyed through the dryer, generally through a number of zones where different conditions are maintained.[1]

Atmospheric Cabinet Dryers.—This type is made in many different modifications, but practically all fall within two general classifications: (1) those dryers in which the material is supported on trays placed by hand on shelves within the drying cabinet, and (2) those in which the trays are wheeled into the cabinet on trucks. Both types are used extensively for handling many products such as pigments, dyes and other granular and pasty materials. In the truck type of tray dryer, operations may either be on the batch system or may be semicontinuous, in that one or more trucks may be run into the dryer at intervals, while an equal number of trucks are removed at the same time from the other end. By this method of operation, the material progresses through the dryer in a semicontinuous manner.

Vacuum Dryers.—Vacuum drying is required for many products which would be injured by the higher temperature of atmospheric drying. Furthermore, in some cases, vacuum drying is more economical because its heat can be supplied at low temperature by means of exhaust steam. Frequently, drying under vacuum is much more rapid than atmospheric drying. Vacuum dryers for solids are similar to the atmospheric cabinet dryers mentioned above, except that the cabinet is of much heavier construction, adapted to be held under vacuum, and provided with a condenser and vacuum pump.

Automatic Continuous Conveyor Dryers.—A great many dryers of this type have been developed. Any sort of conveyor suited to the product may be used. Such conveyors include nontilting and tilting pans, belts of various sorts, traveling buckets, rolls for handling web and sheet materials, festoon carriers, and chain conveyors for hauling tray trucks. One form, known as the *stock dryer*, is used for fibrous material and generally employs a wire-cloth conveyor belt.

[1] Alliot, E. A., *Trans. Inst. Chem. Engrs.* (*London*), **2**, 93 (1924); Kershaw, F., *Ind. Eng. Chem.*, **30**, 1115 (1938).

Rotary Dryers.—Rotary dryers are of several sorts, with the principal variations concerning the method of supplying heat. In the simplest form, the dryer consists of a slightly sloping cylinder, open at both ends and supported on tires rolling on wheels. The material is fed at one end, and fuel (gas, oil or powdered coal) is burned at the other end. A typical capacity report on rotary dryers is given in Table 58. When products of combustion must be kept separate from the material, combustion may take place in a central tube or in a furnace surrounding the dryer, or air heated by steam coils in a separate chamber is blown into the dryer. Numerous variations are possible, but the fundamental differences depend only on whether the heating medium supplies its heat to the material undergoing drying by direct or indirect contact.[1]

Agitator Dryers.—Such dryers generally consist of a vertical cylindrical shell 5 to 6 ft. in diameter, provided with a steam jacket and a heavy slow-speed agitator for scraping the bottom. They are useful for the handling of pastes and sludges as well as caking crystals and various noncaking materials such as wood flour and other dynamite "dope" ingredients. Material is fed through an opening in the top and raked from a door in the side. These dryers may be operated either under atmospheric pressure or under vacuum, in the former case showing a steam consumption of about 1¾ lb. per pound of moisture evaporated.

Drum Dryers.—When materials are to be carried from solution to the dry state in one operation, the drum dryer is generally employed. This consists of either one or two drums on the surface of which the material to be dried is sprayed in a thin film. The heating medium is conducted to the inside of the drum. As soon as the material has been dried, it is scraped from the surface of the drum. The principal variations of construction in *atmospheric drum dryers* relate to the number of drums and to the method of applying the solution.

When drying must be carried from solution to solid under low-temperature conditions, *vacuum drum dryers* are sometimes employed. Such equipment is similar to the single-drum dryer mentioned above, except that the drum must be enclosed in a chamber capable of evacuation. Furthermore, means must be provided for discharging the solids without breaking the vacuum.

[1] Harrigan, H. W., and J. A. Boyd, *Chem. Met. Eng.*, **46**, 214 (1939).

TABLE 58.—REPRESENTATIVE TESTS OF RUGGLES-COLES DRYERS

Type and size	XA-8	XA-10	XA-14	XA-14	XA-18	XB-8	XB-14	XF-14	H-8
Material	Clay	Coal	Coal	Stone	Ore	Clay	Clay	Stone	Flotation concentrates
Moisture in material fed, %	24.5	9.0	11.8	8.9	14.2	27.3	19.8	5.2	12.5
Moisture in material discharged, %	2.7	0.6	1.1	0.7	4.7	0.7	1.3	0.3	3.2
Temperature of outside air, °F	52	28	65	74	40	50	70	47	38
Temperature of fan exhaust, °F	140	128	168	145	165	226	221	390	355
Temperature of material fed, °F	50	40	63	70	48	58	64	50	41
Temperature of material discharged, °F	305	240	245	280	220	237	248	360	238
Type of fuel	Coal	Coal	Coal	Coal	Oil	Coal	Oil	Coal	Oil
Calorific value of fuel, B.t.u. per lb. or gal	13,000	13,200	13,900	14,000	144,000	12,405	138,000	14,000	14,100
Fuel consumed per hour, lb. or gal	265	305	715	940	143	280	65.8	1,260	24.7
Horsepower required for dryer drum	11	16	48	53	73	12	54	56	10.5
Horsepower required for dryer fan or fans	3	4	9	9.5	16	4.5	16	11	3.5
Capacity, dried material per hour, lb	7,256	22,000	46,000	76,400	98,500	3,915	18,500	104,000	13,100
Water evaporated per hour	2,096	2,031	5,580	7,096	10,906	1,414	4,267	5,375	1,392
Water evaporated per lb. or gal. of fuel	7.9	6.66	7.8	7.55	76.2	5.05	64.8	4.27	56.3
Fuel per ton (2,000 lb.) of dried material, pounds or gallons	73	27.8	31.1	24.6	2.91	142	7.1	24.3	3.77
Total thermal efficiency	76.9	76.3	77.7	77.0	79.4	50.5	58.2	54.2	58.7

TABLE 59.—SAMPLE OF INQUIRY SHEET

The C. O. Bartlett & Snow Co.,
6200 Harvard Avenue
Cleveland, Ohio

Gentlemen:

Kindly furnish us with specifications and approximate cost of a dryer of the correct type for the following use:

1. Material to be dried..

....

2. Tons of wet material to be dried in one hour...................................

....

3. Size of lumps, grains or particles..

....

4. Per cent of moisture in material in natural condition........................

....

5. Per cent of moisture desired in final condition..................................

Rough sketch of floor plan showing location of other machines	....
	6. Special conditions........................
	....
	....
	....
	....
	....
	....
	....
	....

Name..

Company...

City...State....................................

Spray Dryers.—Spray dryers generally consist of a chamber through which heated air passes upward, countercurrent to the fall of finely divided droplets of the material to be dried. The spray of material is produced either by conducting the solution under pressure to spray heads, or by turbine type dispersers. The bottom of the drying chamber ordinarily contains some form of conveyor for removing the dried material. Such dryers are employed in the manufacture of soap powder, milk powder and similar materials.[1]

Table 59 is typical of the inquiry sheets supplied by dryer manufacturers.

Suggested Collateral Reading

Materials of Construction

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[1] GILL, A. H., *The Engineer*, **105,** 511 (1923); KLEINSCHMIDT, R. V., and B. B. FOLGER, *Ind. Eng. Chem.*, **30,** 1372 (1938); LEWIS, H., *Ind. Chemist*, **10,** 439, 499 (1934).

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WERKING, L. C.: Impervious Carbon Equipment, *Chem. Met. Eng.*, **46**, 362 (1939).
WHITTAKER, H. F.: Materials of Construction for Chemical Apparatus, *Trans. Am. Inst. Chem. Engrs.*, **15**, 114 (1923).
Your Materials Handbook, *Chem. Met. Eng.*, **43**, 518–564 (1936).

General Equipment

Advances in Equipment, *Chem. Met. Eng.*, **46**, 689, 722 (1939).
BOOMER, E. H.: Design of High Pressure Laboratory Equipment, *Can. Chem. Met.*, **17**, 136 (1933).
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CHAPTER XI

CHEMICAL ENGINEERING PLANT LAYOUT AND ELEVATION

Rational plant design is essential in chemical engineering industries for many reasons, among them, the need for minimizing of such equipment hazards as corrosion, fire and explosion, and personal hazards from fume and poison. Furthermore, only through rational design is it possible to provide for those strict production economies necessary to commodities that serve as raw materials for other industries, and seldom reach the market without processing. The form of a building should be a function of its purpose, and the discharge of this purpose in the best possible manner requires that the beginning should be made in plant layout.

Plant design involves the arrangement of (1) product, process and by-product storage facilities, (2) materials-handling equipment, and (3) process equipment, in efficient coordination with regard to other factors such as future expansion of production, economical distribution of process steam and power, possible hazards and personnel welfare. Field[1] has presented a plan for aiding in the development of a fundamental design, based upon schematic diagrams to illustrate the underlying relationships between storage space, flow of materials and future expansion. First, the elementary development of plant layout is carried out to show only the fundamental relationships between storage and operating machines. Then follows rearrangement based upon segregation of operations and storage. After this, consideration is given to changes based upon the above, with added weight given to expansion, allocating storage and production facilities to provide for both limited and unlimited expansion. Revisions based upon the irregularity or inequality of growth in all departments must then be worked into the plan.

[1] FIELD, CROSBY, *Chem. Met. Eng.*, **32**, 794 (1925).

Facilities required for a process consist essentially of places and equipment for the storage of the various materials used and produced, for carrying on the several operations, and for moving the materials to and from the processing and storage places. Their design is predicated on the assumption that the usual services found in an existing establishment will be available, including steam and electric power, water, fuel, sewers and waste disposal means, locker and washrooms, maintenance shops, fire and police protection, communications, and so on. A layout involving an entirely new site would require essentially all these facilities, the design of which is a job of considerable magnitude in itself. However, if the process under consideration is an addition to an existing plant, it will be necessary only to make a study of present service facilities to ascertain just what increases are needed to take care of the new process.

Essential Factors in Planning Layout.—The three factors necessary for the general plan of any plant are: (1) the starting point, or location, or reference point; (2) a kinematic diagram or directional factor; and (3) a statement of the space requirements for various product and by-product storage facilities and for processing departments. From known, calculated or estimated space requirements for individual equipment, it is possible to obtain proper allocations of equipment and the over-all dimensions of the building. The last two factors usually are summarized together before the design of a project is completed.

Principles of Plant Layout.—H. T. Moore[1] has suggested the following points as preliminary to final action in matters of layout and arrangement and equipment selection:

1. Desired capacity of plant, and estimated future capacity.
2. Divisions of manufacturing schedule, to determine number and variety of finished units to be produced.
3. A list of materials or parts comprising product, to determine which ones will be manufactured and which ones purchased and stored.
4. Production equipment or plant facilities needed for desired capacity of initial plant, including any special provisions or structural features which will facilitate production.
5. A study of manufacturing and assembling operations necessary to produce a finished or subassembled unit, to check proper spacing of equipment.

[1] Moore, H. T., *Mech. Eng.*, **47**, 1059 (1926).

6. Time interval required between successive operations, if any, to check need for and location of storage space.

7. Sequence of operations in manufacturing and assembly departments in order that departments and equipment should be in logical and convenient relationship for progressive flow of materials.

8. Space requirements per department to house production equipment and provide space needed for aisles, storage or auxiliary departments.

9. A review of various operations entering process to determine whether certain departments should be isolated from standpoint of safety, noise or special process needs.

10. A summary of floor-space needs of initial plant, determining which areas can be proportionally increased for different departments, based on an assumed future capacity after a certain period of years, thus providing an approximate basis for estimating space requirements and thus developing a suitable layout for ultimate plant expansion.

A set of guiding principles for layout should be drafted to enable the establishment of an ideal, no matter what the actual conditions. The determination of just what these guiding principles are for any specific problem is a matter of fundamental importance. For a specific problem assume that the guiding principles agreed upon by Woodward[1] are as follows:

1. Simplification of equipment sizes and materials of construction, and the use of standard designs instead of special designs. These are cheaper in first cost and cost less to maintain.

2. Grouping of like operations so that one group of operators can tend to all equipment of the same kind.

3. Interchangeability of use of like equipment so as to provide a maximum of flexibility.

4. Type of equipment and its arrangement to be such as to permit any part or practically all of it to be repiped in suitable fashion for use on other processes of a similar nature, without need for the relocation of any of the major pieces.

5. Use of automatic and semiautomatic controls to be as extensive as an economic study shows possible (and a little farther, as well). This also applies to the use of materials-handling equipment.

6. Since the proposed operations are nonhazardous and nontoxic, no special ventilation will be required, other than that necessary for good working conditions.

[1] WOODWARD, R., *Chem. Met. Eng.*, **48**, 5—92 (1941).

Specifically for chemical plants, it is necessary to bear in mind the special process hazards to equipment, buildings and personnel.

Plan and Elevation of Plant.[1]—Rational design must include arrangement of processing areas, storage areas and handling areas, in efficient coordination and with regard to such factors as:

1. Expansion.
2. Economic distribution of water, process steam, power.
3. Economic use of floor space.
4. Building requirements.
5. Possible hazards of fire, explosion, fumes.
6. Health and welfare of workers.
7. Geographical limitations.
8. Materials handling.

Methods of Studying Plans.—The acquisition of quantitative data and specifications on individual equipment having been accomplished, the next step in design is to decide upon the proper arrangement of the equipment and storage and to provide for expansion. There are many ways of accomplishing this. One method is to draw to scale the floor plan in as many arrangements as the engineer feels can be made, bearing in mind the considerations for correct design and noting on each sheet the advantages and disadvantages of each design. Another method is to make cardboard cutouts to scale of the floor plan of each piece of equipment and arrange these upon a cross-sectioned sheet or table, studying each arrangement and recording notes on each plan worked out. To sit down with conferees to work out rational arrangements develops the imagination and wits and permits immediate discussion of the many moves and minor rearrangements.

Storage.—Storage facilities for raw materials and intermediate and finished products may be located in isolated areas or in adjoining areas. Hazardous materials become a decided menace to life and property when stored in large quantities and should consequently be isolated. Storage in adjoining areas to reduce materials handling may introduce an obstacle toward future expansion of the plant. Field[2] has introduced a novel method of

[1] Woodward, R., *Chem. Met. Eng.*, **39**, 552 (1932).
[2] Field, Crosby, *Chem. Met. Eng.*, **32**, 794 (1925).

study of plant arrangement to determine this point of storage area location or orientation. Arranging storage of materials so as to facilitate or simplify handling is also a point to be considered in design. Where it is possible to pump a single material to an elevation so that subsequent handling can be accomplished by gravity into intermediate reaction and storage units, costs can be greatly reduced. Liquids can be stored in small containers, barrels, horizontal or vertical tanks and vats, either indoors or out of doors.

Equipment.—In making a layout, ample space should be assigned to each piece of equipment; accessibility is an important factor. Unless a process is well seasoned, it is not always possible to predict just how its various units may have to be changed in order to be in harmony with each other. This is especially true if the process is being developed from pilot-plant-scale operation, as usually carried out, with equipment not specially designed for the process. It is well known that in chemical manufacturing, processes may be adopted which appear to be sound after a reasonable amount of investigation in the pilot-plant stage, yet frequently require minor or even major changes before all parts are properly operating together.

It is extremely poor economy to fit the equipment layout too closely into a building. A slightly larger building than appears necessary will cost little more than one that will just fit. The extra cost will indeed be small in comparison with the penalties that will be extracted if, in order to iron out the kinks, the building must be expanded.

The operations that constitute a process are essentially a series of unit operations that may be carried on simultaneously. These include filtration, evaporation, crystallization, separation, drying, and others. Since these operations are repeated several times in the flow of materials, it should be possible to arrange the necessary equipment into groups of the same kinds. This sort of layout will make possible a division of operating labor so that one or two operators can be detailed to tend all equipment of a like nature.

The relative levels of the several pieces of equipment and their accessories determine their placement. Although gravity flow is usually preferable, it is not altogether necessary because liquids can be transported by blowing or by pumping, and solids can be

moved by mechanical means. Gravity flow may be said to cost nothing to operate, whereas the various mechanical means of transportation involve the first cost of the necessary equipment and the cost of operation and maintenance. However, gravity flow usually means a multistory layout, whereas the factors favoring a single-story plant may largely, if not entirely, compensate for the cost of mechanical transportation.

Plant Expansion.—Expansion must always be kept in mind. The question of multiplying the number of units or increasing the size of the prevailing unit or units merits more study than it can be given here. Suffice it to say that one must exercise engineering judgment; that as a penalty for bad judgment, scrapping of present serviceable equipment constitutes but one phase, for shutdown due to remodeling may involve a greater loss of money than that due to rejected equipment. Nevertheless, the cost of change must sometimes be borne, for the economies of larger units may, in the end, make replacement imperative.

Floor Space.—Floor space may or may not be a major factor in the design of a particular plant. The advantages and disadvantages of single-story and multiple-story factory buildings are discussed in Chap. VI. The value of land may be a considerable item. The engineer should, however, follow the rule of practicing economy of floor space, consistent with good housekeeping in the plant and with proper consideration given to line flow of materials, access to equipment, space to permit working on parts of equipment that need frequent servicing, and safety and comfort of the operators.

Utilities Servicing.—The distribution of gas, air, water, steam, power and electricity is not always a major item, inasmuch as the flexibility of distribution of these services permits designing to meet almost any condition. But a little regard for the proper placement of each of these services, practicing good design, aids in ease of operation, orderliness and reduction in costs of maintenance. No pipes should be laid on the floor or between the floor and the 6-ft. level, where the operator must pass or work. Chaotic arrangement of piping invites chaotic operation of the plant. The flexibility of standard pipe fittings and power-transmission mechanism renders this problem one of minor difficulty.

Building.—After a complete study of quantitative factors, the selection of the building or buildings must be considered. Standard factory buildings are to be desired, but, if none can be found satisfactory to handle the space and process requirements of the chemical engineer, then a competent architect should be consulted to design a building around the process—not a beautiful structure into which a process *must* fit. It is fundamental in chemical engineering industries that the buildings should be built around the process, instead of the process being made to fit buildings of conventional design.

What consideration must be given to buildings depends upon conditions. If the designer must adapt his design to fit an old building, or building space already erected, his problem is cut out for him and he has his limiting conditions. However, the selection of the design of the building to meet the requirements of the process is more scientific. In this case, one finds before him practically all types of standard building, built in units, interlocking or otherwise, ready for shipment and erection (see Chap. VI).

Miscellaneous Items.—Throughout chemical industry, much thought must be given to the disposal of waste liquors, fumes, dusts and gases. Ventilation, fume elimination and drainage may require the installation of extra equipment. This may involve the design of the individual pieces of operating equipment, or it may require the installation of isolated equipment. If the latter be the case, the location of such equipment where it will not interfere with the flow of materials in process should be practiced. The selection of the proper piece of equipment for doing this sevice is also an important point; the less attention the ventilating, fume or waste-elimination systems require, the better service they may render. Sometimes air conditioning of the plant is called for and may require an elaborate setup. But the installation of such equipment, when needed, pays in better service from operators, less discomfort, greater production and a better morale than when such conditions are left to nature.

It must be recognized that there is not only one solution to the problem of layout of the equipment. There are many rational designs. Which plan to adopt must be decided upon after exercise of engineering judgment and after striking a balance of the advantages and disadvantages of each possible choice.

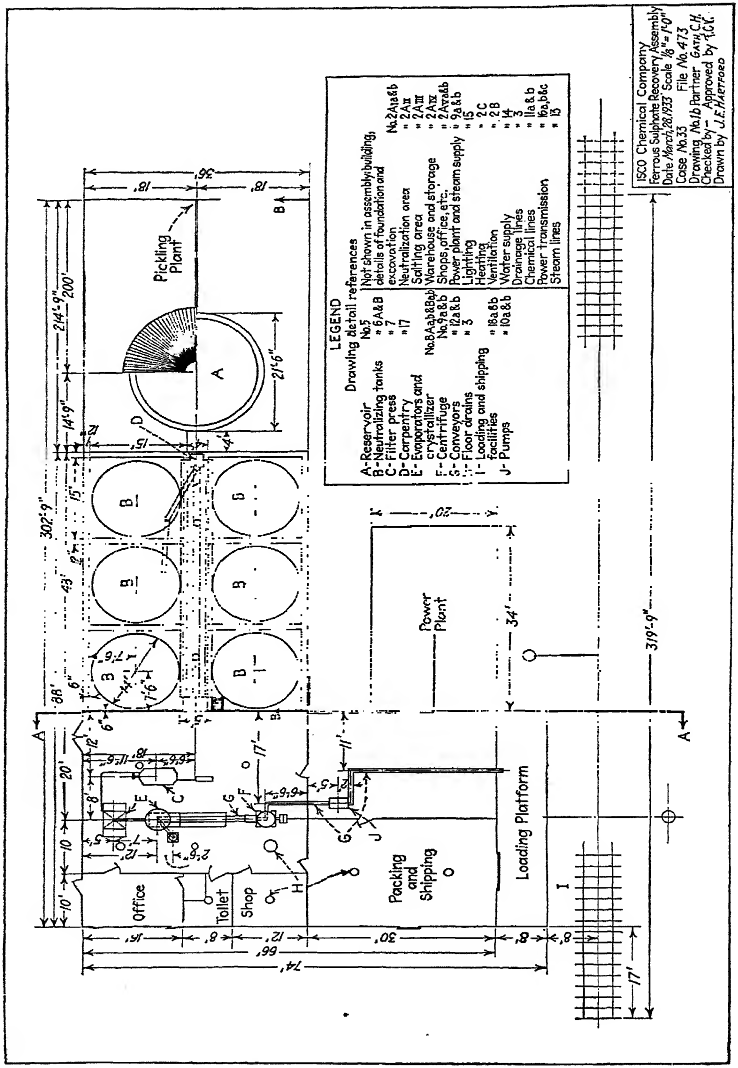


FIG. 48.—Typical assembly plan.

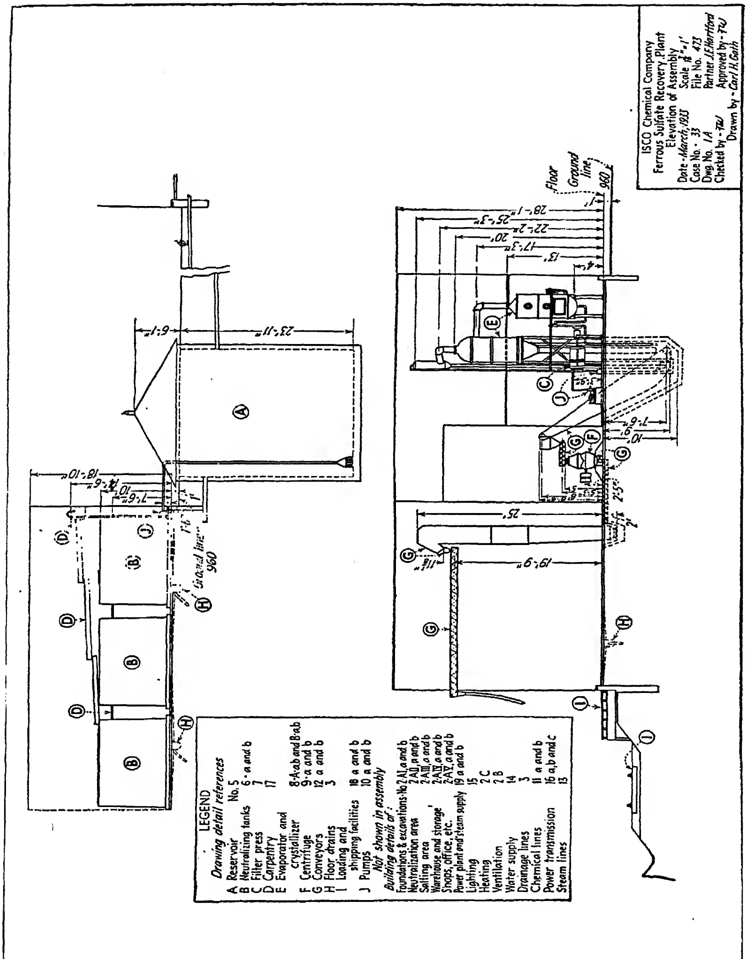


FIG. 49.—Typical assembly elevation.

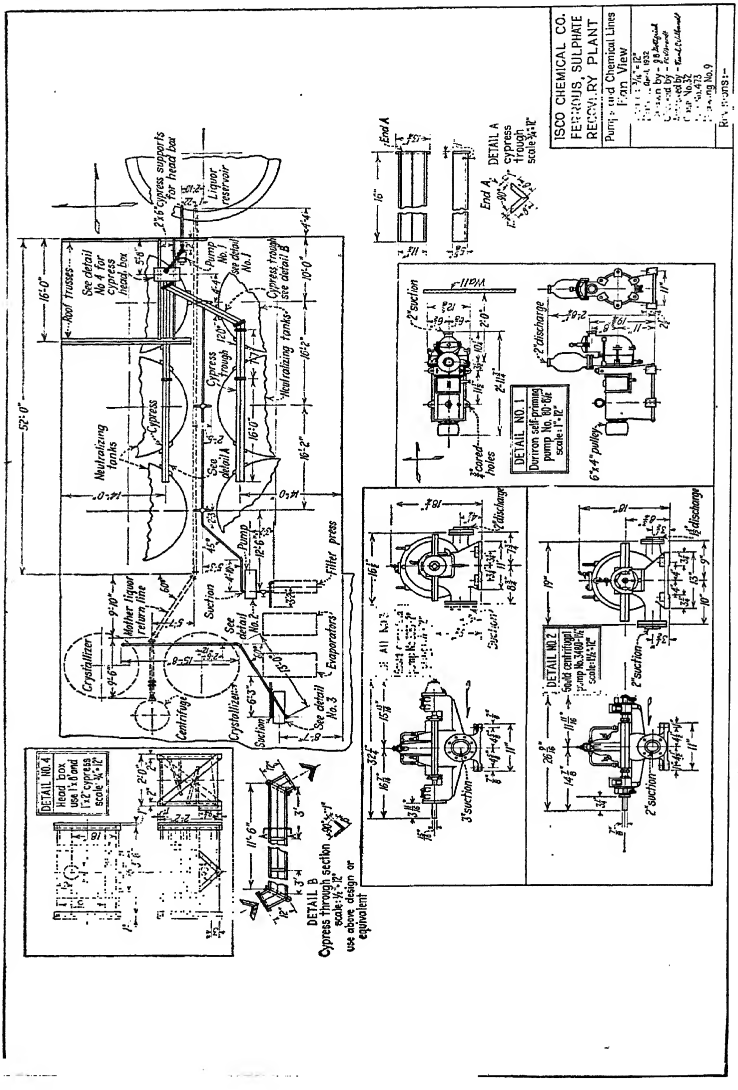


FIG. 50.—Typical plan of pumps and piping, with details.

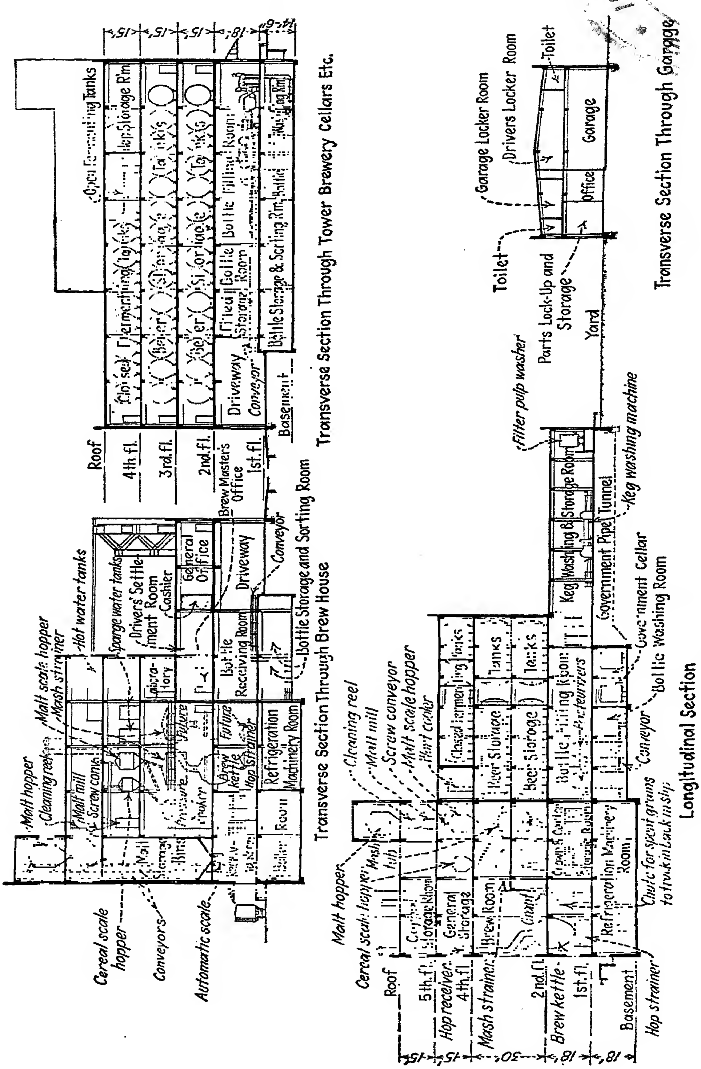


FIG. 51.—Sectional elevations of a brewery. (*Victor Buhr, Food Ind.*, **5**, 123*ff.*, 1933.)

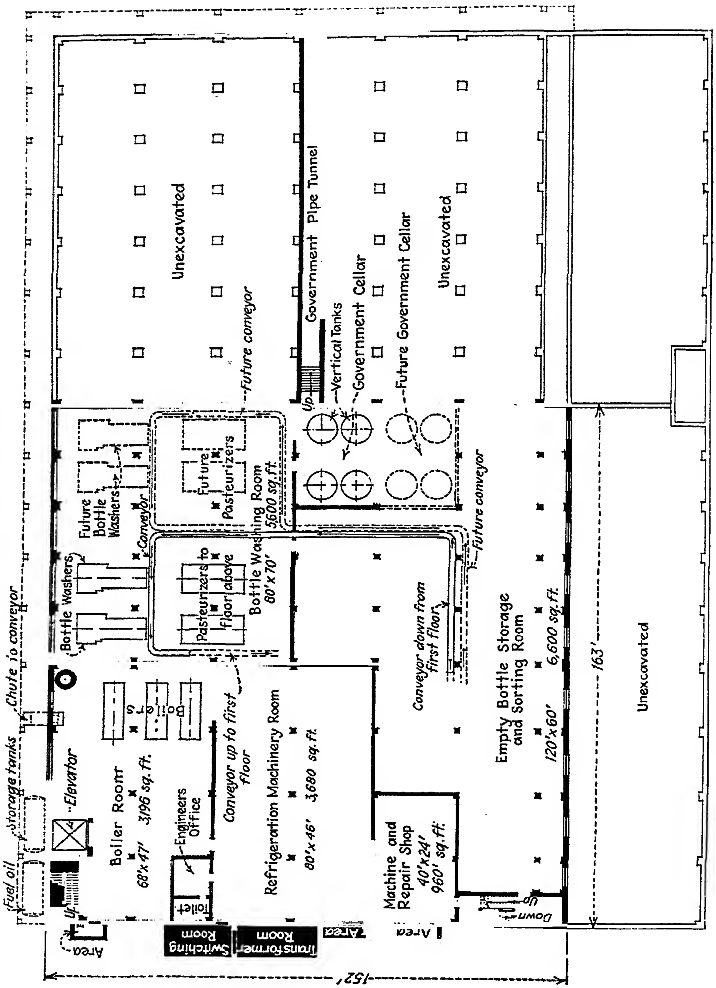


FIG. 52*a*.—Basement plan of a brewery. (*Victor Buhr, Food Ind.*, **5**, 123*ff.*, 1933.)

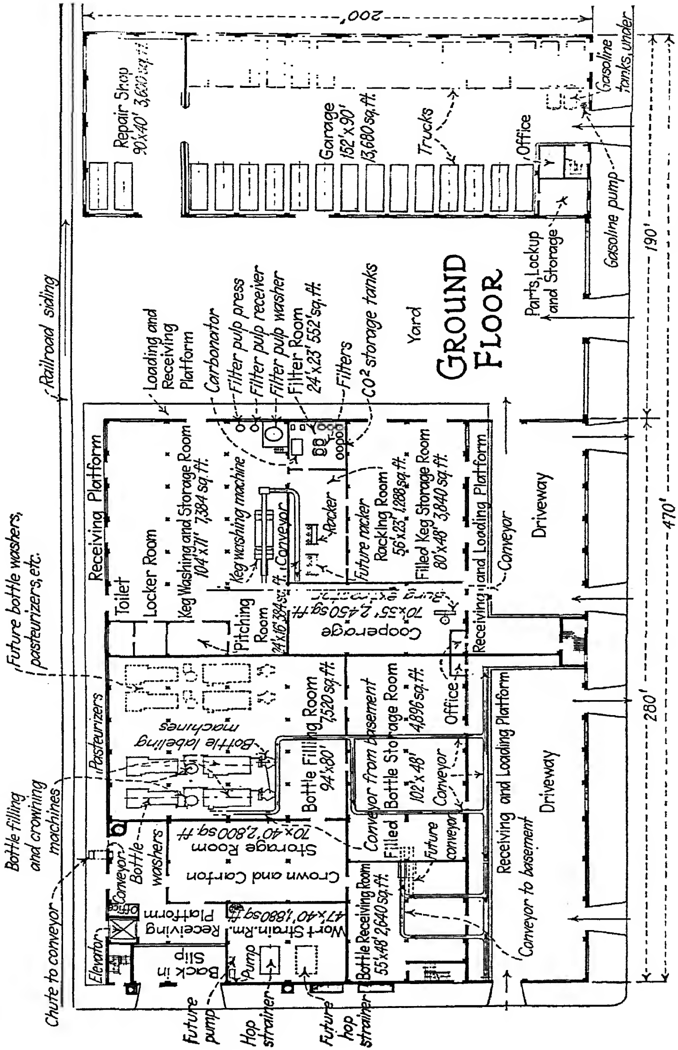


FIG. 52b.—Ground floor plan of a brewery. (*Victor Buhr, Food Ind.*, **5**, 123*ff.*, 1933.)

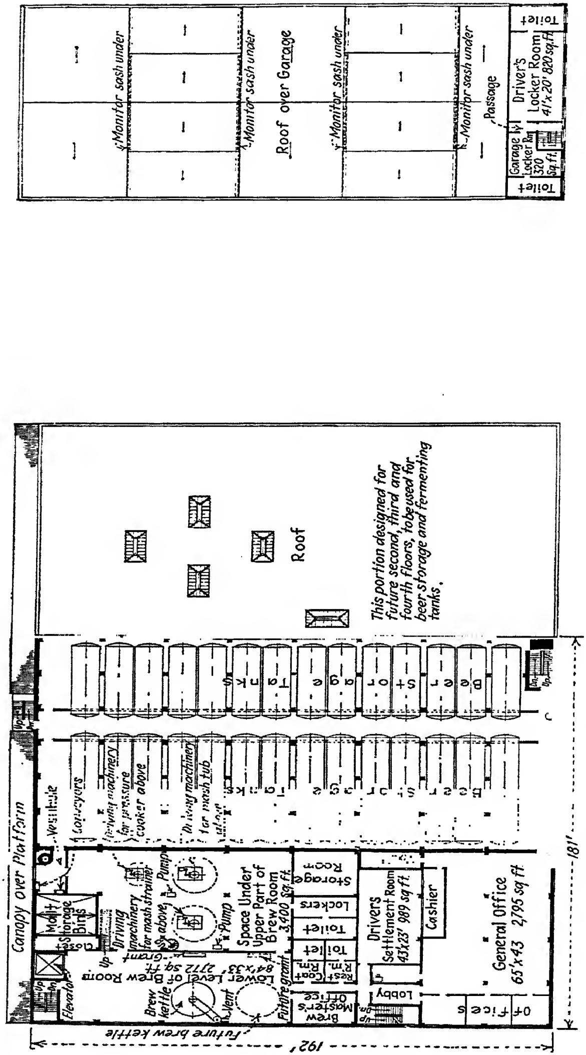
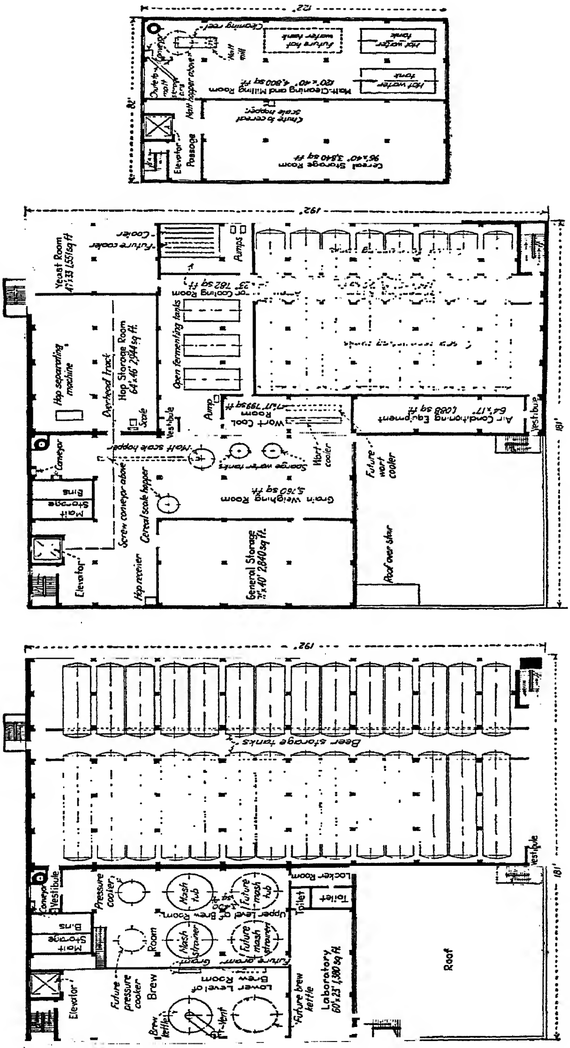


Fig. 52c.—Second-floor plan of a brewery. (*Victor Buhr, Food Ind.*, **5**, 123*ff.*, 1933.)



d e f

FIG. 52*d*, *e*, *f*.—Third-, fourth- and fifth-floor plans of a brewery. (*Victor Buhr*, *Food Ind.*, **5**, 123*ff.*, 1933.)

Materials-handling Equipment.—Consideration of equipment for materials handling need be only a minor factor in most cases of arrangement, owing to the multiplicity of available materials-handling devices. But where this operation is paramount in a process, then serious thought must be given to it. Again it should be repeated that engineering judgment must be exercised, for the exigencies of the case will constitute the major factor in the decision. Whenever possible one should take advantage of the topography of the land, if such will serve to advantage in the process.

Sketching Plans, Elevations and Equipment.—After consultation with other engineers or the examination of plans on similar projects offered by equipment manufacturers who provide such service, the next step is the recording of the selected layout. Some examples of plans and elevations of assemblies and equipment installations are presented in Figs. 48 to 52*a* to *f*.

Suggested Collateral Reading

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CHAPTER XII

PRECONSTRUCTION COST ACCOUNTING

There are many phases to cost accounting in an industrial plant, but the designer of a new plant is interested primarily in preconstruction cost accounting, later in operation cost accounting. The fundamental principles that apply to operation cost accounting, however, also apply to preconstruction, but the application of the data so obtained is different. In the instance of operation cost accounting on an existing plant, one wishes to know whether efficient operation is in force, and to seek out and correct errors of commission or omission. In preconstruction costs, which includes operation costs before possible operation, one hopes to seek out any such possible errors and correct them before they actually occur. The purpose and result of preconstruction cost accounting is, therefore, to permit the making of a brief report, showing what possibilities exist for profits and earnings under proper management, even before the investment is made.

Costs.—The purpose behind the publication of the costs and other economic factors tabulated in this chapter is to aid in the solution of problems having to do with complete or partial chemical plant operations.

These data have been collected from a variety of sources, and no uniform method has been used in deriving them. The correlation of such a mass of data naturally shows adjustments, assumptions and discrepancies when considered in relation to any one plant. In the hands of competent engineers who have the experience to give proper weight to the variables which may or may not be shown, such data justify consideration. The values used in this chapter cannot be guaranteed but should be used only as an index to give relative data. For close estimation, current prices should be obtained from manufacturers.

Aside from the assurance that preconstruction cost accounting gives, that an investment in a process is justified, it has the

further value of stopping further expenditure in processes which would be uneconomic. In this connection Becket[1] has stated:

> By assuming theoretical yields from the chemical or electrochemical reactions [in the proposed process], which are oftentimes interestingly clever, and by further taking the most optimistic view of all other factors that an experienced, reasonably intelligent engineer would dare to assume, it has been possible by cost estimating in this way to convince many who have experimented diligently that they have been seeking a worthless goal. The saddest instances revealed by this method are those in which mental energy and capital have been wasted to a much greater extent, in which the technology of a process has been carried to successful demonstration on a minor scale and for which great economy has been forecast in the operation of a plant of commercial size. In cases of the latter class cost estimates had been prepared by the proponents.

The following schedule portrays the general lines upon which a cost estimate may be drawn. From this the novice can derive constructive suggestions, although some of the initiated may criticize it as obvious and, therefore, unnecessary. Nevertheless, it is presented with confidence in its value, since experience has shown that the timely use of even this slight assistance toward approximate cost prediction would have saved a vast amount of work which is known to have been wasted in foredoomed undertakings.

TYPICAL SCHEDULE FOR COST ESTIMATION IN CHEMICAL INDUSTRIES

1. Producing costs.
   - *a*. Basic raw materials delivered.
   - *b*. Other process materials.
   - *c*. Power: electrochemical and mechanical.
   - *d*. Fuel.
   - *e*. Process tools and supplies.
   - *f*. Repair materials: equipment and structures.
   - *g*. Packages.
   - *h*. Manufacturing wages.
   - *i*. Repair wages: equipment and structures.
   - *j*. Works salaries.
   - *k*. Works general expense.
2. Management and marketing.
   - *a*. Salaries.
   - *b*. Rent.
   - *c*. Accounting.
   - *d*. Selling.
   - *e*. Legal service.
   - *f*. General expense.

[1] BECKET, F. M., *Chem. Met. Eng.*, **33**, 283 (1926).

3. Capital costs.
   a. Amortization.
   b. Depreciation.
   c. Insurance.
   d. Taxes.

The principal object of such a schedule is to ensure that no important item of cost shall be forgotten. Naturally, each class of process will call for modification of any typical schedule. A mechanical guide of this kind is of great assistance even to the experienced estimator.

Before attempting to predetermine costs, it is a logical procedure to select an appropriate scale of operation and then to visualize the complete plant and organization required for the desired end. However clearly a process may have been conceived as a succession of chemical reactions and unit operations, cost estimating each material and operation develops a clearer picture of the producing and economic structures; and the mental courage requisite to develop a thorough cost estimate will find its reward in an enhanced understanding of the project. In every case the estimate deserves careful analysis. An estimate that reflects favorably on the process will show points of strength and of relative weakness, so that further work can be directed toward factors in which further economies should be sought or can most easily be secured. The autopsy on an unfortunate process will usually reveal the principal cause of failure and will at least dictate the need of a new line of attack. If the product is already being made by another method, an estimate of the corresponding cost may wisely be attempted, since, however ingenious a new process, its competitive utility will be slight if the cost is relatively high. Clearly a cost estimate is the logical nucleus around which to gather data for the complete engineering report which the critical executive desires.

A slightly different sort of preconstruction cost estimating is that which seeks to estimate costs for the semicommercial plant, rather than the final one. Weiss and Downs[1] have given the following:

Outline of Cost Estimate for Semicommercial Scale Manufacture

1. Direct raw material cost.
2. Direct labor cost.
3. Ordinary overhead.
   a. Indirect material, such as supplies and packages.
   b. Indirect labor, such as supervision, control chemists, watchmen and maintenance men.

[1] Weiss, J. H., and C. R. Downs, "The Technical Organization," p. 165, McGraw-Hill Book Company, Inc., New York, 1924.

  c. General service charges, such as heat, light, power, compressed air and water.
  d. General fixed charges on the capital invested, such as interest, taxes, insurance and a rental charge.
4. Extraordinary overhead incidental to experimental manufacture.
  a. Repairs.
  b. Alterations.
  c. Technical supervision.
  d. Depreciation and obsolescence, as determined by subtracting the scrap value of the plant from the original cost erected.

Adjustment of Budgets to Variable Production.—In like manner, budgets for other materials and for direct labor could be made for the process; but, when overhead is considered,

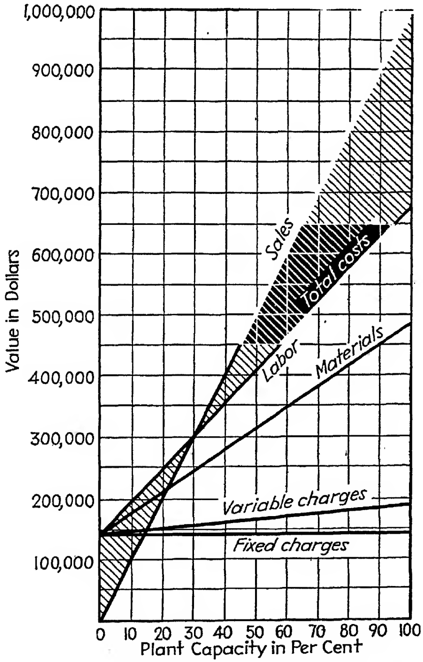

Fig. 53.—The graphic basis of a budget.

another factor comes into play—the variation of such expense with variation in output. Hence, for several definite operating capacities, corresponding overhead expense budgets should be established, in order to determine the exact structure of the budget for any output, whether for 25, 50, 75, or 100 per cent of normal capacity. Rautenstrauch[1] does this graphically in the following manner:

First, the cost accounts are grouped in four classes:

1. Direct materials, varying directly with production.
2. Direct labor, varying directly with production.
3. Variable charges, such as indirect materials, indirect labor, supplies and the like, which vary with the production.
4. Fixed charges, which do not vary with production but are substantially constant. Such charges include interest on the investment, depreciation, insurance, taxes and the like.

The historic cost records are next analyzed, in order to set standards of expense for variable charges. Obviously, direct materials, direct labor and fixed charges can be computed without any analysis of the cost accounts. Only those charges that vary with production must be computed in order to make the chart. Figure 53 shows such a chart as constructed by Rautenstrauch from actual plant data, a summary of which follows. An analysis of the operating statement at 65 per cent of normal plant capacity showed that:

	Total Costs	Percentage, Based on Sales
Direct material cost	\$195,000	30
Direct labor cost	130,000	20
Variable charges	32,500	5
Fixed charges	130,000	20
Sales	650,000	100
Profit	162,500	25

The normal capacity of the plant is \$1,000,000 in sales per year, and, with these data, the graph can be constructed. It will be noted that below \$300,000, or 30 per cent of annual sales, a loss will be incurred and that at any other given plant capacity a limit for expenses is established. No attempt should be made to budget expenses precisely until the machinery of cost accounting has been working smoothly for a sufficient length of time.

[1] RAUTENSTRAUCH, W., *Chem. Met. Eng.*, **27**, 415 (1922).

A. RAW MATERIALS COSTS

The cost of raw materials and value of by-products and products must be determined from statistics in the company office or from a study of long-time price curves from such sources as the U. S. Census of Manufactures, *Chemical & Metallurgical Engineering*, *Industrial & Engineering Chemistry*, *Chemical Industries*, *Oil, Paint and Drug Reporter*, and the daily papers. Fluctuations of prices are taken into consideration by striking an average or seeking the normal price. Steam, water, gas, air or any material that enters into the production of the chemical product must be included in the materials costs. Ferrous and nonferrous alloys vary considerably in price, but a range of $0.065 to $0.075 per pound is generally applied to cast iron, with mild steel $0.04 to $0.05 per pound higher. Stainless steels can be produced as low as $0.23 per pound, but $0.35 is still considered a fair evaluation.

Costs of power, steam, gas, water, electricity, raw materials are itemized and totaled. Water costs vary, but it may be considered that $0.05 per 1,000 gal. is a normal water rate when the company pumps its own wells. According to Blake and Purdy[1] steam costs range from $0.22 to $0.35 per 1,000 lb., depending on the cost of fuel, size of units, load factor and labor cost. Electricity costs per kilowatt-hour, including all charges, average $0.0125 for industrial uses in the United States. Table 60 is a compilation of the averages in the individual states based on three different scales of demand. Gas at $0.50 per 1,000 cu. ft. is a fair figure. A request from the local chamber of commerce or public utilities in the community selected will secure authentic data for that community.

Bass and Mease[2] point out that reduction in costs may be obtained by setting up several material balances on raw materials used in several competing processes.

Building, Equipment and Installation Costs.—The next consideration in preconstruction cost accounting concerns itself with the bill of materials for land, building and all equipment; this includes labor of erection as well as costs of all items. Most of

[1] Perry, J. H., "Chemical Engineers' Handbook," 2d ed., pp. 2488–2493, McGraw-Hill Book Company, Inc., New York, 1941.

[2] Bass, L. W., and E. R. Mease, *Chem. Met. Eng.*, **45**, 426 (1938).

TABLE 60.—NET PRICE OF ELECTRICITY AVERAGE CHARGE PER KILOWATT-HOUR FOR INDUSTRIAL SERVICE[1]
January 1, 1939

Billing demand Monthly consumption	150 kw. 30,000 kw.-hr.	300 kw. 60,000 kw.-hr.	1000 kw. 200,000 kw.-hr.
State	Cents per kw.-hr.	Cents per kw.-hr.	Cents per kw.-hr.
Alabama	1.58	1.48	1.37
Arizona	2.36	2.23	1.98
Arkansas	1.82	1.68	1.58
California	1.31	1.13	0.98
Colorado	1.89	1.78	1.62
Connecticut	1.87	1.68	1.49
Delaware	1.82	1.61	1.38
Florida	2.15	2.01	1.72
Georgia	1.67	1.53	1.30
Idaho	1.76	1.69	1.56
Illinois	2.19	1.90	1.47
Indiana	1.85	1.72	1.49
Iowa	1.88	1.73	1.51
Kansas	1.82	1.71	1.52
Kentucky	1.84	1.64	1.42
Louisiana	1.88	1.60	1.39
Maine	1.70	1.70	1.49
Maryland	2.07	1.61	1.60
Massachusetts	2.01	1.79	1.58
Michigan	2.11	1.97	1.70
Minnesota	1.92	1.72	1.46
Mississippi	1.93	1.77	1.57
Missouri	1.66	1.56	1.44
Montana	1.35	1.28	1.17
Nebraska	1.74	1.64	1.32
Nevada	1.67	1.17	1.06
New Hampshire	1.69	1.58	1.42
New Jersey	2.01	1.78	1.54
New Mexico	2.15	2.13	2.12
New York	2.08	1.82	1.54
North Carolina	1.57	1.48	1.39
North Dakota	2.19	1.96	1.68
Ohio	1.89	1.67	1.32
Oklahoma	1.75	1.62	1.44
Oregon	1.40	1.27	1.11
Pennsylvania	1.74	1.55	1.37
Rhode Island	1.83	1.72	1.48
South Carolina	1.70	1.53	1.33
South Dakota	2.23	2.06	1.88
Tennessee	1.56	1.40	1.20
Texas	1.89	1.69	1.43
Utah	1.50	1.50	1.50
Vermont	1.66	1.54	1.46
Virginia	1.62	1.45	1.22
Washington	1.52	1.34	1.18
West Virginia	1.83	1.63	1.39
Wisconsin	1.94	1.78	1.51
Wyoming	2.38	2.13	1.84

[1] From Federal Power Commission Report, FPC-R-17.

this information is available from manufacturers of the equipment or from their published price lists. In addition, there are available many operation cost data on equipment in textbooks and in trade literature. The private files of the engineer often supply much of this. The listing of the items in the bill of materials is quite simple and is taken in its entirety from the drawings and blueprints of the process. The burden of completeness lies wholly upon completeness of the design and written specifications. The addition of the values and correct summation are merely items of stenography, or bookkeeping, or both.

B. STRUCTURE BUILDING COSTS

For purposes of comparison it is customary to express building costs on a square foot or cubic foot basis. These unit costs are influenced by many factors, *viz.*, the type of construction, local labor costs, local material costs, the size of the building, the ratio of wall perimeter to floor area, etc. A unit cost for one building should not be used in estimating the cost of another unless the conditions are similar.

In reinforced-concrete storage buildings, multistory, 250 lb. load per square foot, costing between $53,000 and $200,000, cost per cubic foot varies between $0.096 and 0.072, or between $1.18 and $0.86 per square foot. For light manufactories, multistory, 12-ft. story height, 200-lb. load and buildings costing between $50,000 and $400,000, the cubic foot cost varies between $0.21 and $0.10, while the square foot cost varies between $1.10 and $2.50. One-story mill-construction brick buildings cost between $0.92 and $1.90 per square foot for buildings of areas of 100 by 500 ft. and 50 by 25 ft., respectively.

In Table 61 the cubic foot costs are given for a one-story simple type of industrial building 60 by 150 ft. with an average height of 35 ft. The building is of steel frame construction, with ordinary concrete foundations, and a 6-in. concrete floor slab. Forty per cent of the wall area consists of steel sash and doors. The material for the walls and roof vary as shown in the tabulation. No allowance has been made for lighting, heating, or other building equipment.

It is possible for the cubic foot costs of industrial buildings to vary from $0.05 to $0.06 for large cheaply constructed type to $0.35 to $0.40 for a well-built modern administration building.

Table 62 gives an approximation of relative costs of various types of industrial building on the square foot basis.

Schaphorst[1] has developed a nomograph showing approximate construction costs from building dimensions.

TABLE 61.—CUBIC FOOT COSTS OF A BUILDING[1]

Type of material		Approximate cost per cubic foot
Walls	Roof	
Face brick, common backing, 8-in. total	Tar and gravel on gypsum plank	$0.098
Common brick, 8-in.	Tar and gravel on gypsum plank	0.093
Hollow tile, 8-in.	Tar and gravel on gypsum plank	0.085
Corrugated asbestos	Corrugated asbestos	0.078
Corrugated iron	Corrugated iron	0.073

[1] ROUNDS, H. P., and J. T. KIERNAN, Building Fabrication and Comparative Costs *Chem. Met. Eng.*, **48**, 5—106 (1941).

Foundations and Excavations.[2]—One can safely figure piling, wood, concrete or steel, to cost per lineal foot in place $1 to $3, respectively, in ground which will permit straight and easy driving. Excavation costs for the average small foundation for machinery or building in soft dirt or clay are of the order of $3 a cubic yard. Wooden forms for concrete can be placed at $0.30 to $0.35 a square foot. For heavier foundations these figures will average as follows: excavation, $2 a cubic yard; forms $0.30 a square foot; and concrete, $10 a cubic yard. A concrete conduit tunnel will cost approximately $8 per running foot, *whereas* a larger walking tunnel averages $18 per foot.

Flooring.—For a chemical plant where leakage of acid or alkali is possible, a concrete floor is not at all desirable. There is a tendency to crack and spall around the I-beams. The dilute acid runs down along the walls or pilasters and very quickly attacks and corrodes the steel. Such a construction combined with steel and concrete walls will not last over a period of five

[1] SCHAPHORST, W. F., Calculating Construction Costs, *Ind. Eng. Chem.* (*News ed.*), **25**, 1151 (1941).

[2] PARKER, H. R., *Chem. Met. Eng.*, **33**, 545 (1926).

or six years. In a very short time the floors become rough and a source of high maintenance. An acid brick, laid on cement, will give a smooth, permanent and easily maintained floor at a cost very little above concrete.

For upper floors a very serviceable and reasonably priced floor can be obtained by the use of a heavy, thick tile laid in asphalt or tar on a concrete subbase. Such a floor is more quickly laid than acid brick and serves practically as well.

TABLE 62.—APPROXIMATE RELATION OF COSTS OF INDUSTRIAL BUILDINGS OF VARIOUS TYPES[1]

Type of buildings	Cost per square foot of floor area	
	Fire-resisting	Fireproof
Multistory buildings for light manufacturing	\$1.70–\$2.15	\$2.00–\$2.50
Multistory buildings for heavy manufacturing	2.00– 2.50	2.30– 2.85
Multistory warehouses	1.70– 2.15	2.00– 2.50
Single-story buildings for general manufacturing	1.65– 2.10	1.90– 2.40
Single-story buildings for heavy manufacturing	1.90– 2.40	2.20– 2.75
Single-story warehouses	1.40– 1.75	1.70– 2.20
Foundries	\$3.00–\$4.00	
Forge shops (exclusive of hammer foundations)	3.00– 4.50	
Press and stamping (exclusive of press foundations)	2.75– 4.50	
Heavy machine shops (exclusive of machine foundations)	3.00– 4.50	

[1] KAHN, M., *Factory Management and Maintenance*, **95**, 54 (1937).

Approximate costs of a few types of flooring are given in Table 63. For purposes of comparison these costs have been calculated on a floor load of 200 lb. per square foot. (See also Fig. 54.)

Walls and Roofs.—Walls and roofs constitute a lesser problem in chemical plants than flooring, except where fume attack and fire hazards are present. Tables 64, 65, and 66, together with Fig. 55, include the essential data on wall types, materials and costs of walls.

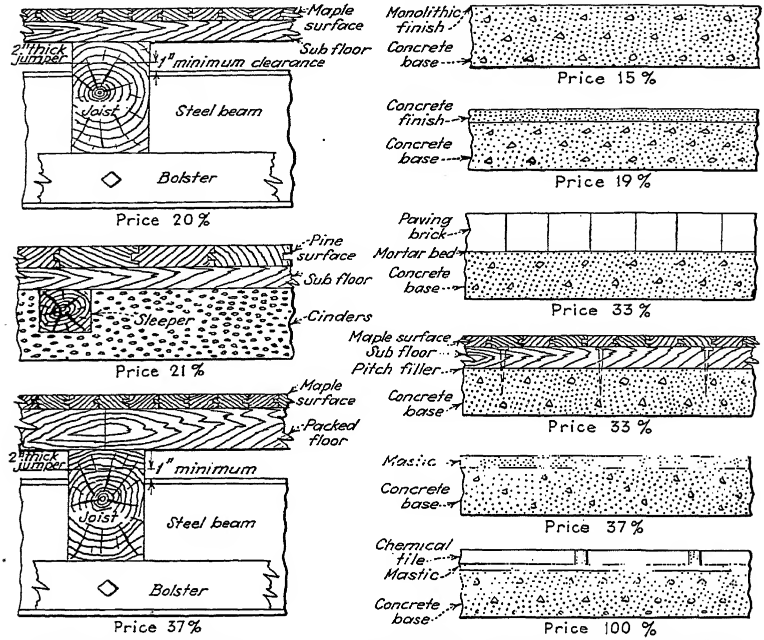

FIG. 54.—Approximate cost of various forms of factory floor construction, expressed in percentage of cost of most expensive floor shown. [*H. E. Stitt*, *Chem. Met. Eng.*, **38**, 196 (1931).]

TABLE 63.—COST OF FLOORINGS[1]

Material	Type	Cost per square foot
Wood	2-in. block alone	$0.25
	2-in. block on concrete	0.60
	Planks on joists	0.30
	Wood on concrete	0.55
	Standard hardwood double floor	0.55
Concrete	Cement on ground	0.25
	Cement on upper floors	0.50
Steel	Checker plate, 3/8 in.	1.15
	Grating	1.35
Brick	Tile in cement on a concrete subbase	0.70
	Acidproof, on concrete	0.75
Special conditions	Lead pan	1.30
	Mastic on concrete	0.65

[1] PARKER, H. R., *Chem. Met. Eng.*, **33**, 546 (1926).

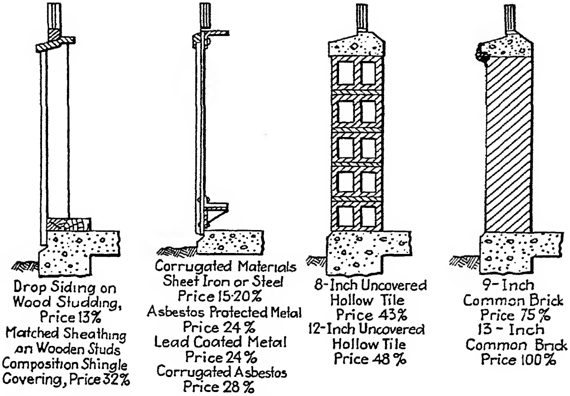

FIG. 55.—Approximate cost of various forms of wall construction. Expressed in percentage of cost of most expensive type shown (*Stitt, loc. cit.*)

TABLE 64.—WALL MATERIALS[1]
(See also Fig. 55)

Material	Type	Cost per square foot	Cost per square foot			
			Curtain walls		Building walls	
			6-in.	8-in.	12-in.	16-in.
Common brick	Solid air space	.....	.....	$0.75	$1.20	$1.60
Concrete......	Block	.....	$0.45	0.55		
	Solid	.....	0.45	0.55	0.70	
Tile..........	Hollow	.....	0.30	0.40		
Steel.........	Corrugated iron, 26 gage	$0.22				
	Asbestos covered	0.27				
Wood.........	Shingle	0.20				
	Clapboard	0.20				
Special conditions.......	Gypsum, 3 in.	0.25				
	Cement, covered, 1½ in.	0.32				
	Asbestos, ¼ in.	0.40				

[1] PARKER, H. R., *Chem. Met. Eng.*, **33**, 546 (1926).

TABLE 65.—COST OF FOUNDATIONS AND WALLS IN BRICK MILL BUILDINGS OF SLOW-BURNING CONSTRUCTION[1]

	Number of stories					
	One	Two	Three	Four	Five	Six
Foundations, including excavations, cost per lineal foot						
Outside walls	$2.00	$2.90	$3.80	$4.70	$5.60	$6.50
Inside walls	1.75	2.25	2.80	3.40	3.90	4.50
Brick walls, cost per square foot of surface						
Outside walls	0.40	0.44	0.47	0.50	0.53	0.57
Inside walls	0.40	0.40	0.40	0.43	0.45	0.47

[1] ALFORD, L. P., "Management's Handbook," p. 282, The Ronald Press Company, New York, 1924.

A wooden building may be made fireproof by the use of the cement gun to coat the interior with a layer of cement. The tabulation of Table 66 gives the results of a job of coating 6,000 sq. ft. with cement about 1½ in. thick:

TABLE 66.—COST OF CEMENT-COATING WOODEN BUILDING[1]

Cement-gun crew and outfit	$43.20 per day
Carpenters	0.75 per hour
Laborers	0.50 per hour
Cement	3.90 per barrel
Sand	1.40 per cu. yd.
Metal	0.04 per sq. ft.
Total time	45 hr.
3 coats applied	
Square feet covered per hour	135 sq. ft.

	Material	Labor	
Rental of outfit		$ 432.00	
Applying lath		476.00	
Applying cement		318.00	
Cement, 85 bbl	$331.00		
Sand, 40 yd	56.00		
Miscellaneous material and power	80.00		
Metal lath	240.00		
Total	$707.00	$1,226.00	$1,933.00

Unit Costs	Material	Labor	Total
Metal lath	$0.040	$0.080	$0.120
Cement	0.076	0.125	0.201
Total cost per square foot	$0.116	$0.205	$0.321

[1] PARKER, H. R., *Chem. Met. Eng.*, **33**, 547 (1926).

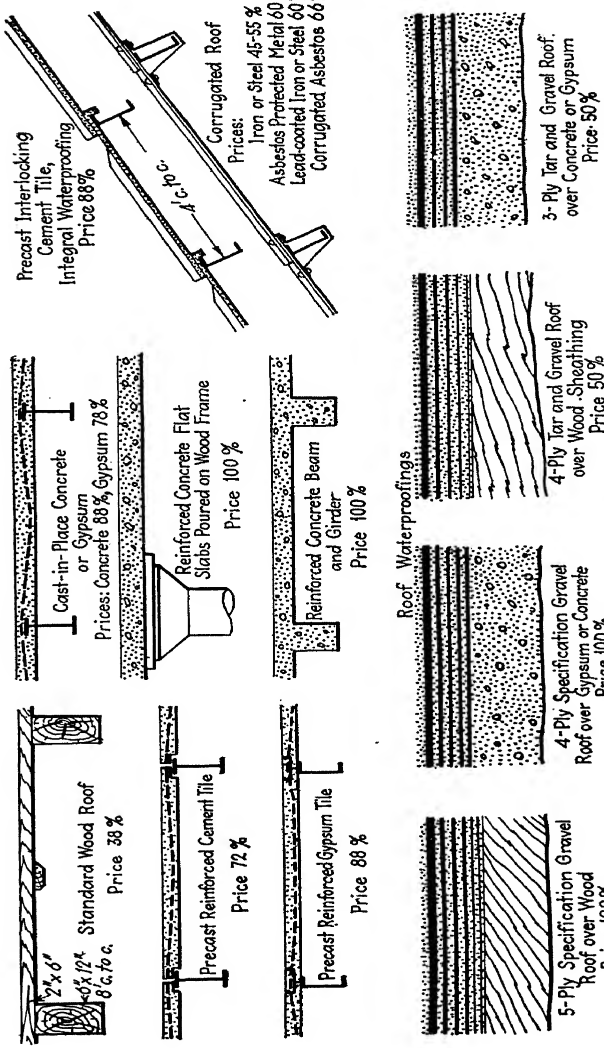

FIG. 56.—Approximate cost of various forms of factory roof structure and roof waterproofing. Expressed in percentage of cost of the most expensive type shown. [*Stitt, Chem. Met. Eng.*, 38, 196 (1931).]

TABLE 67.—COST PER SQUARE FOOT OF ROOFING MATERIALS[1]
(See also Fig. 52)

Wood shingles	$0.10	Slate	$0.40
Planks with tar and gravel specification	0.20	Tile	0.40
Corrugated iron	0.20	Asbestos	0.35
Tin on planks	0.25	Concrete, tar and gravel	0.30
Copper on planks	0.60	Gypsum, precast tile plus tar roofing paper	0.30
Lead on planks, 4 lb	0.80	Glass	1.25
Zinc on planks	0.40		

Building costs per unit material, labor only:

Wood	$25–$50 per 1,000 board feet
Steel	¾–1½ cts. per pound

[1] PARKER, H. R., *Chem. Met. Eng.*, **33**, 546 (1926).

TABLE 68.—COST OF HEATING INSTALLATIONS, STEAM
(Based on building volume, 0°F. outside, 60°F. inside)

Enclosed volume of building, cu. ft.	Pipe radiators[1]		Fin radiators[2]		
	Sq. ft. at 5-lb. steam pressure	Including supply and return lines	Sq. ft. at 5-lb. steam pressure	Including fans	Motor hp.
50,000	320	$ 300	50	$ 235	1/6
100,000	630	550	100	325	1/3
150,000	950	750	150	525	1/2
250,000	1,600	1,150	250	950	1
500,000	3,200	2,200	500	1,800	2
1,000,000	6,300	4,000	1,000	3,600	4
2,000,000	12,500	8,000	2,000	7,000	8

[1] Pipe radiation based upon 0.4–0.5 ct. per cubic foot volume of mill building, from construction costs, etc.

[2] Fin radiation based upon manufacturers' estimates, including allowance for outlets and intakes, freight, piping and installation. Air-blast systems cost approximately same as pipe radiation.

Refrigeration.—A refrigeration unit of 20 tons per day will cost between $200 and $300.

Cost of Lighting Equipment.—Figures on the cost of lighting equipment used in lighting a miniature lamp factory, using 300-watt lamps and an energy consumption of 3 watts per square foot, appear in Table 69.

TABLE 69.—COST OF LIGHTING EQUIPMENT

Equipment	Cost per Outlet
Fittings	$ 2.21
Conduit	0.94
Wire	1.94
Panel boards	2.04
Miscellaneous supplies	0.51
Miscellaneous	0.22
Fixtures	4.71
Switches	0.12
Total (not including lamp)	$12.69

Overhead lighting expense includes depreciation on the original installation to return the investment, plus interest and maintenance. Considering a possible complete replacement in 6 years, depreciation must be charged at the rate of 1.4 per cent of first cost per month. Interest at 6 per cent per year, on the declining principal, would be 18 per cent of first cost in 6 years, or 0.25 per cent per month. Proper maintenance expense will usually average less than ⅓ per cent of first cost per month—use 0.35 per cent. Total overhead lighting expense is thus 2 per cent (1.4 plus 0.25 plus 0.35 per cent) per month, assuming complete replacement in 6 years.

C. EQUIPMENT COSTS

An excellent compilation of costs of process equipment and accessories, including data on pipes and tubings, fittings, heat exchangers, pumps, thickeners, filters, driers, absorption towers, and packing has been made by Bliss.[1]

1. MATERIALS HANDLING

If the capitalization of the wages of an average worker, on the basis of the average net return from the capital employed in the industry, may be assumed to be between $10,000 and $15,000, equipment for which cost and maintenance equal this amount may be installed for each worker. However, the nature of the work often controls the type of labor required, whether mechanical or human, and this factor must be given more con-

[1] BLISS, H., *Trans. Amer. Inst. Chem. Engr.*, **37**, 763—803 (1941).

sideration than the capitalization costs. The variety of equipment available for handling chemical products often complicates the selection, but the decision oftentimes depends upon cost of the service rendered. Data on cost of mechanical handling of chemical products are given by Montgomery in Perry's "Chemical Engineers' Handbook," Sec. 20.

a. Belt Conveyors.

TABLE 70.—PERFORMANCE AND COST DATA ON BELT CONVEYORS[1]
(Basis: 100 ft. between centers)

Belt width, in.	Material weight, 50 lb. per cu. ft.			Material weight, 100 lb. per cu. ft.			Approximate price, not assembled
	Belt speed, ft. per min.	Capacity, tons per hr.	Theoretical motor hp.	Belt speed, ft. per min.	Capacity, tons per hr.	Theoretical motor hp.	
18	250	65	0.928	250	130	1.46	$ 615
20	250	80	1.09	250	160	1.73	670
24	250	115	1.48	300	276	2.83	850
30	300	216	2.44	350	504	4.66	1,040
36	300	312	3.16	350	740	6.13	1,350

[1] Chain Belt Co.

b. Apron Conveyors.

TABLE 71.—PERFORMANCE AND COST DATA ON APRON CONVEYORS[1]

Pitch of conveyor, in.	Length of apron, in.	Capacity, tons per hr.	Horse power for 50-ft. centers	Approximate price, not assembled
6	18	21	1.6	$ 660
6	24	28	1.8	720
6	30	35	2.1	780
6	36	42	2.2	840
9	42	57	2.3	930
9	48	66	2.3	970
12	54	106	2.3	1,045
12	60	117	2.3	1,070

[1] Chain Belt Co.

c. Bucket Elevators.

30 ft. of 6- by 4-in. buckets, no casings but otherwise complete, $ 350
30 ft. of 16- by 8-in. buckets, no casings but otherwise complete, 1,100

TABLE 72.—PERFORMANCE AND COST DATA FOR BUCKET ELEVATORS[1]

Size, in.	Capacity on material weighing 100 lb. per cu. ft.	Horse power	Approximate list price
6 × 4	7.1	1.07	$1,250
8 × 5	14.8	2.22	2,110
10 × 6	26.6	4.00	3,162
12 × 6	32.0	4.80	3,790
14 × 7	50.9	7.60	5,170
15 × 7	77.7	11.6	5,910
16 × 7	83.0	12.4	6,550

[1] Chain Belt Co.

d. Screw Conveyors.

TABLE 73.—PERFORMANCE OF SCREW CONVEYORS[1]

Size, in.	Capacity, cu. ft. per hr.			Horse power required			Recommended speed, r.p.m.		
	A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
6	315	175	130	0.0835	0.13	0.19	160	100	65
9	1,100	600	440	0.269	0.45	0.72	150	95	60
10	1,400	......	......	0.377	......	......	140		
12	2,260	1,280	980	0.539	0.985	1.68	120	85	55
14	3,600	1,930	1,450	0.915	1.50	2.52	120	80	55
16	5,400	2,700	2,000	1.40	2.09	3.50	120	75	50

A = light, nonabrasive material, as grain.
B = heavy, nonabrasive material, as coal.
C = heavy, abrasive material, as sand.

Screw-conveyor troughs of black iron vary in cost from $3 a foot in length for the 6-in. diameter trough to $9 a foot for the 16-in. size; the galvanized trough is approximately one-third more costly.

[1] Chain Belt Co.

e. Suction Conveyors.

Pneumatic conveyor to move 10 tons per hour of 40 lb. per cu. ft. material a distance of 300 ft., $7,500

TABLE 74.—PERFORMANCE AND COST DATA ON SUCTION CONVEYORS

Size, in.	Capacity for 50 lb. per cu. ft. material, tons per hr.	Horse power	List price
2	7.7	2.2	$ 720
4	30.8	8.8	3,000
6	69.3	19.8	6,460
8	123.1	35.2	11,500
10	192.5	55.0	18,000
12	277.0	79.2	25,900

f. **Wagon Unloader.**—Overhead, motor operated, 1 hp., $ 400
g. **Portable-platform Elevator.**—Four-ton capacity, 1,750

2. SIZE REDUCTION

A review[1] of crushing and grinding costs has been compiled for a selected group of materials on several classes of milling equipment. Table 75 is a general table on power requirements and costs for the four grades of size reduction.

TABLE 75.—SIZE REDUCTION POWER REQUIREMENTS AND COSTS[1]

Classification, tons per day	Breaking or coarse crushing (12 in.–2 in.)	Intermediate crushing (2 in.–¼ in.)	Fine grinding (¼ in.—50 mesh)	Pulverizing (50–200 mesh)
	Kilowatt-hours per ton			
15,000	0.50	1.5	5.0	4.0
5,000	0.75	2.0	7.0	5.0
1,500	1.25	2.5	10.0	8.0
500	4.50	4.5	13.0	10.0
150	7.00	7.0	30.0	30.0
50	12.00	12.0	40.0	40.0
15	20.00	20.0	50.0	50.0
	Crushing costs, dollars per ton			
15,000	$0.01	$0.03	$0.10	$0.08
5,000	0.015	0.04	0.15	0.10
1,500	0.07	0.07	0.20	0.15
500	0.10	0.10	0.30	0.25
150	0.15	0.15	0.75	0.75
50	0.25	0.25	1.00	1.00
15	0.40	0.40	1.50	1.50

[1] Basis per 24-hr., day.

[1] FUWA, T., *Chem. Met. Eng.*, **30**, 268 (1924).

a. Cone Crusher.

TABLE 76.—PERFORMANCE AND COST DATA ON CONE CRUSHERS FOR COARSE GRINDING[1]

Size cone, ft.	Size of product, inches: 5/8	3/4	1	1 1/4	1 1/2	2	Horse power	Cost
	Capacity, tons per hour (average)							
2	30	35	45	50	60	...	30	$ 3,500
3	55	70	80	85	90	95	60	5,500
4	100	120	150	170	...	185	100	8,000
5 1/2	160	200	275	300	...	375	200	15,000
7	280	330	450	560	600	790	300	23,000

[1] Nordburg Manufacturing Co.

b. Pebble Mills.

TABLE 77.—PERFORMANCE AND COST DATA ON PEBBLE MILLS[1]

Size, feet	Hourly capacity: Sand, pounds	Hourly capacity: Semipaste, gallons	Horse power	Cost
1 × 1 1/2	40	6 1/2	3/4	$ 100
2 1/2 × 3 1/2	250	42	3	750
3 × 4	450	80	5	1,000
3 1/2 × 4	680	110	6	1,100
4 1/2 × 3 1/2	1,000	170	8	1,450
4 1/2 × 4 1/2	1,350	225	8 3/4	1,550
5 × 6	2,200	385	12	2,150
6 × 5	2,750	460	15	2,600
6 × 8	4,650	775	22	3,325
6 × 10	6,300	1,000	30	4,150

[1] Patterson Foundry & Machine Co.

c. Tube Mills.

Tube mills grinding 1 3/4 tons of feldspar per hour cost approximately $20,000, with all accessories included, but not including the necessary building.

A complete plant which will grind in the neighborhood of 2 tons of feldspar per hour, 98 per cent through 200 mesh, with a feed through 1/2 in., costs approximately $45,000 complete, including the building, primary crusher, elevator from the crusher to the storage bin, storage bin, all the necessary fittings, tube mill, elevator from the tube mill to the separator and elevator returning the tailings to the mill, finished product elevator, a 150-ft. self-conveyor and a structural steel building 35 by 60 ft.

d. Ball Mills.

Ball mills with the essential accessories included, for grinding 26 tons of limestone per hour, would cost $4,500; and $11,000 for grinding 50 tons of barytes. Ball mills, without accessories, for dry grinding of medium limestone, range in cost from $2,250 to $14,500 for capacities between 1¾ tons per hour, of 1½-in. to 10 mesh, or 1¼ tons of 1-in. to 48 mesh, to 36 tons per hour of 1½-in. to 10 mesh, or 25 tons of 1-in. to 48 mesh; the horsepower requirements range between 28 and 325.

Ball mills, without accessories, for wet grinding range in costs between $1,400 and $17,000, with capacities ranging from 1 to 20 tons per hour, grinding from 1½ in. to 10 mesh and ¼ in. to 200 mesh, at an expenditure of power ranging between 9 and 320 hp.

e. Rod Mills.

TABLE 78.—PERFORMANCE AND COST DATA ON LOW-CAPACITY ROD MILLS[1]

Size, ft.	Mesh 8	20	35	48	65	100	Horse power	Approximate cost
	Capacity, tons per hour, medium-hard rock, 1 in.							
2 × 4	1	⅘	⅔	½	⅓	⅕	6	$1,160
3 × 6	3	2½	2	1½	1⅓	⅔	17	1,740
3 × 8	4	3	2½	2	1½	1	26	3,140
4 × 8	10½	7½	6⅓	5¼	3¾	2	47	4,650
4 × 10	12½	10½	7½	6⅓	4½	2½	57	5,100

[1] The Mine & Smelter Supply Co.

TABLE 79.—PERFORMANCE AND COST DATA ON HIGH-CAPACITY ROD MILLS[1]

Size, ft.	Mesh 8	20	35	48	65	100	Horse power	Approximate cost
	Capacity, tons per hour, medium-hard rock							
5 × 10	22½	16¼	13¾	11½	8⅓	4½	97	$ 5,875
5 × 12	26	19	16¼	13½	10	5½	120	8,550
6 × 12	33½	25	21	16½	12½	7	145	16,250
7 × 15	53½	40	33½	26½	20	11	170	21,000

[1] The Mine & Smelter Supply Co.

f. Roll Crushers.

TABLE 80.—PERFORMANCE AND COST DATA ON SINGLE-ROLL CRUSHERS[1]

Size, in.	Size product, in.					Size product, in.					Cost
	1¼	1½	2	3	4	1¼	1½	2	3	4	
	Capacity, tons per hour					Horse power					
18 × 18	30	40	55	60	65	11	13	15	12	10	$ 750
18 × 24	40	55	75	80	85	14	18	20	16	12	800
24 × 24	65	90	100	125	140	23	29	27	25	20	1,200
24 × 30	85	120	130	160	180	30	38	35	31	25	1,250
24 × 36	100	130	150	190	210	35	42	40	37	30	1,325
30 × 30	130	170	200	250	270	45	54	53	49	38	1,700
30 × 36	160	210	240	300	330	55	66	62	59	45	1,900
30 × 42	190	240	280	350	380	66	76	74	68	54	2,100
30 × 48	220	280	320	400	440	77	90	86	78	61	2,300
36 × 36	270	350	420	500	510	94	110	110	98	70	3,300
36 × 48	370	470	570	600	770	130	150	150	115	115	3,500

[1] C. O. Bartlett & Snow Co.

TABLE 81.—PERFORMANCE AND COST DATA ON TWO-PAIR ROLL CRUSHERS[1]

Size, in.	Capacity, bu. per hr.		Horse power	Approximate cost
	Meal	Feed		
6 × 12	10	16	3	$ 864
7 × 14	16	25	4	930
7 × 18	25	35	6	990
9 × 14	28	40	8	1,035
9 × 18	35	55	12	1,071
9 × 24	40	70	15	1,122
9 × 30	55	85	17	1,248
10 × 30	60	100	20	1,620
10 × 36	80	120	24	1,812
12 × 30	90	130	27	2,130
12 × 36	100	180	35	2,340

NOTE.—Capacity and horsepower will vary with various kinds of materials and every quality of meal and feed.

[1] The Wolf Co.

g. Attrition Mills.

A complete attrition mill, to grind 50 cwt. of corn per hour, costs approximately $650.

h. Hammer Mills.

TABLE 82.—PERFORMANCE AND COST DATA ON HAMMER MILLS[1]

Size of hopper opening, inches	Size product, inches: 1½	1	¾	Horse power	Approximate cost
	Capacity, tons per hour—based on limestone				
12 × 20	...	...	...	...	$ 480
24 × 40	125	100	75	100	5,100
30 × 40	150	125	100	150	5,700
40 × 40	200	150	125	175	6,300
50 × 40	250	200	150	200	7,000
60 × 40	300	250	200	225	7,700
70 × 40	350	300	250	250	8,300

[1] Dixie Manufacturing Co.

i. Whirlbeater.

A whirlbeater with necessary accessories, to grind 100 cwt. of corn per hour, costs approximately $1,500.

3. MECHANICAL SEPARATION

A compilation[1] on cost of filtration equipment and operation costs has been presented on filter presses, pressure leaf filters and vacuum filters.

a. Screens.

TABLE 83.—PERFORMANCE AND COST DATA FOR HUM-MER SCREENS[1]

Size, ft.	Capacity, tons per hr., coal	Horse power	Cost
4 × 5	56	2	$ 750
4 × 6	80	3	1,025
4 × 7	110	5	1,300
4 × 8	148	7½	1,600

[1] The W. S. Tyler Co.

b. Filter Presses.

Cost of filter presses constructed of metal approximate:

For Al, 1.85, for bronze, 2.75, for lead 2.25 and for stainless steel 4.5 times the base price for cast iron.

See Figs. 57 and 58.

[1] WHITMAN, G., and T. FUWA, *Chem. Met. Eng.*, **30**, 355 (1924).

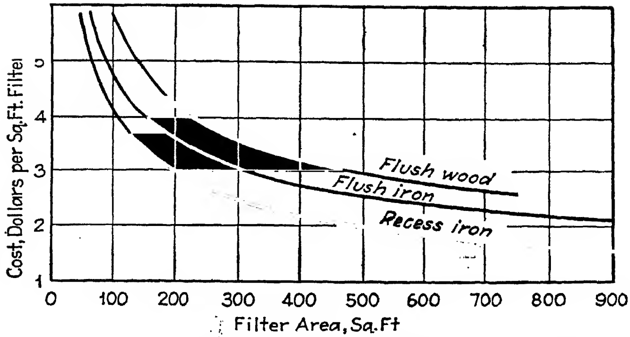

Fig. 57.—Cost of filter presses. Cost, which is expressed in dollars per square foot of filter area, does not include accessory equipment. (*Chaplin Tyler.*)

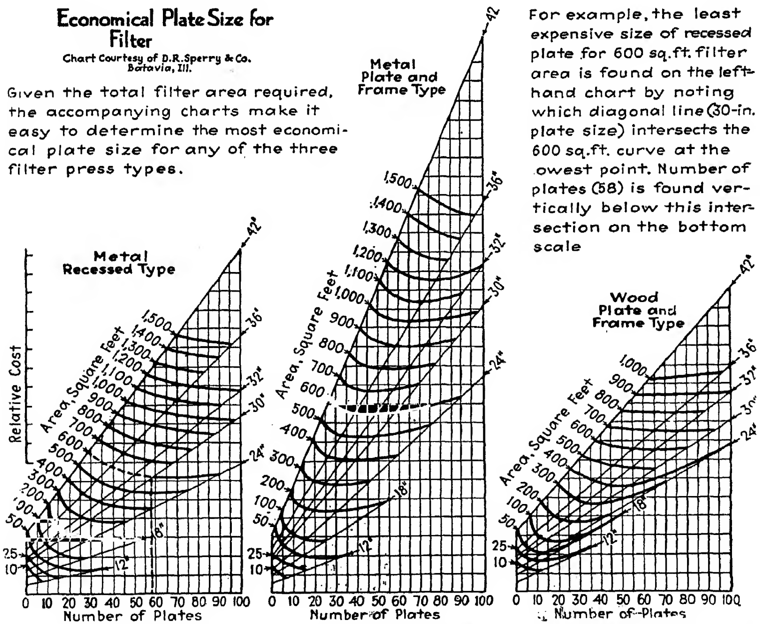

Fig. 58.—Economical plate size for filter presses. (*Chem. Met. Eng.*, *after D. R. Sperry & Co.*)

c. Pressure Leaf Filters.
See Fig. 59.

TABLE 84.—PERFORMANCE AND OPERATION OF KELLY FILTER[1]

Size, sq. ft.	Number of frames	Spacing of frames, inches	Weight of cake, lb. per cycle, 1½-in. cake at 120 lb. per cu. ft.
50	6	4	750
250	8	4	4,050
450	10	4	6,900
650	12	4	9,780

[1] Oliver United Filters, Inc.

TABLE 85.—PERFORMANCE DATA ON SWEETLAND FILTER[1]

Filter area, sq. ft.	Filter-leaf spacing, in.	Number of leaves	Nominal cake capacity, 1-in. cake, cu. ft.
7	3	7	0.58
31	3	12	2.2
131	3	20	10.9
177	3	27	14.7
364	3	36	30.3
695	3	48	57.9

[1] Oliver United Filters, Inc.

Filters of the Kelly type range in cost between \$2,000 and \$7,000, while those of the Sweetland type vary between \$400 and \$6,000.

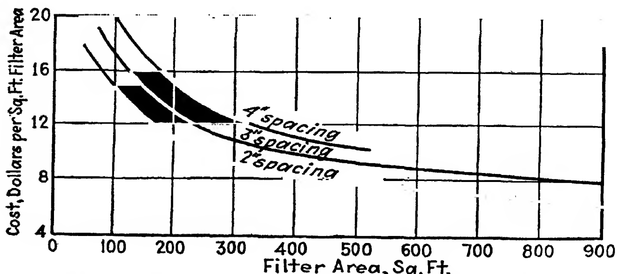

FIG. 59.—Cost of pressure-leaf filters. Cost, which is expressed in dollars per square foot of filter area, does not include accessory equipment. (*Chaplin Tyler.*)

d. **Vacuum Filters.**

See Fig. 60.

TABLE 86.—PERFORMANCE DATA ON OLIVER FILTER[1]

Diameter, ft.	Length, ft.	Area, sq. ft.	Construction	Capacity,[2] tons per hr.	Horse power
3	2	18	Cast-iron drum	5.4	½
4	6	75	Cast-iron drum	22.5	1½
5¼	8	130	Steel	39.0	1½
8	12	300	Steel	90.0	3½
3	4	36	Wood	10.8	1½
5¼	6	100	Wood	30.0	1½
5¼	10	165	Wood	49.5	2
8	10	250	Wood	75.0	3½
11½	14	500	Wood	150.0	3½

[1] Oliver United Filters, Inc.
[2] Based on 600 lb. of material per square foot of area.

TABLE 87.—PERFORMANCE DATA ON AMERICAN FILTER[1]

Filter area, sq. ft.	Diameter of disks, feet	Number of disks	Capacity, tons per hr.	Horse power
22	4	1	6.6	¾
86	4	4	26.4	1
100	6	2	30.0	1
300	6	6	90.0	2
185	8½	2	60.0	1½
375	8½	4	120.0	2
745	8½	8	240.0	3

[1] Oliver United Filters, Inc.

Vacuum filters generally require a greater initial outlay than other types; the Oliver type ranges in cost between $1,400 and $6,500, and the American type between $1,700 and $10,000.

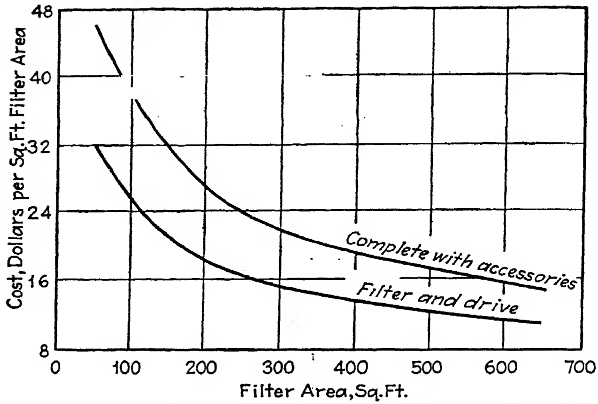

FIG. 60.—Cost of vacuum continuous filters. Cost, which is expressed in dollars per square foot of filter area, is calculated for filter and drive and for filter complete with accessories. (*Chaplin Tyler.*)

e. Extractors.

Type	Size, in.	Capacity				Horse power	Approximate cost
		Rated cubic feet	Bushels	Load, pounds	Speed, r.p.m.		
Base bearing....	26	2½	2	300	1,050	3	$ 950
	40	5	4	500	900	4	1,350
Link suspended..	44	10	8	800	750	5	2,100
	50	17½	14	1,200	650	7½	2,600
Continuous flow.	10	0.21	..	.....	.....	¼	480
	20	1.65	..	.....	.....	1	890
	30	5.80	..	.....	.....	3	1,640
	36	11.70	..	.....	.....	5	2,175
	40	17.40	..	.....	.....	10	2,650
	48	25.10	..	.....	.....	15	4,300

[1] DeLaval Separator Co.

f. Dewaterers.

Vacuum dewaterers, from small to large: $24 to $14 per square foot of filtering area.

g. Classifiers and Thickeners.

Dorr classifier, light duty (iron and steel): \$350 to \$500 per foot width; heavy duty (iron and steel): \$450 to \$950 per foot width.

Akins classifier, heavy duty (submerged): \$500 to \$750 per foot spiral diameter.

Dorr thickener, iron and steel, \$2.50 to \$6.50 per square foot of settling area.

4. Mixing

Table 89.—Performance and Cost Data on Plain and Jacketed Mixers[1]

Diameter, in.	Depth, in.	Capacity, gal.	Horse power	Approximate list price, standard	Approximate list price, jacketed
24	24	47	½	\$175	\$ 260
36	36	155	1	265	365
48	48	375	2	422	547
60	60	735	3	561	691
72	72	1,270	5	720	1,000
84	84	2,000	7½	937	1,482

[1] Patterson Foundry & Machine Co.

Table 90.—Performance and Cost Data on Horizontal Mixers[1]

Capacity, gal.	Capacity, cu. ft.	Width, in.	Height, in.	Length, in.	Horse power	Approximate list price
60	8	18	22	40	¾	\$ 285
185	25	24	30	66	1½	409
470	60	36	40	84	3	672
650	85	42	48	84	5	855
1,000	133	48	56	96	7½	1,163
1,250	166	48	56	120	10	1,400

[1] Patterson Foundry & Machine Co.

5. Heat-transfer Equipment

a. Kettles.

Table 91.—Performance and Cost Data on Jacketed Process Kettles[1]

Capacity, gal.	Diameter, in.	Depth, in.	Horse power	Approximate list price
50	24	28	½	\$ 300
150	36	44	1	420
350	48	55	2	625
725	60	70	3	760
1,250	72	92	5	1,150
1,600	84	92	7½	1,660

[1] Patterson Foundry & Machine Co.

Copper kettle........................... 175-gal. capacity, $150.
Monel metal kettle......................... 175-gal. capacity, $210.
Still kettle, horizontal, steel, 5,000-gal. capacity.............. $1,650.

b. Evaporators.

An economic study of evaporators for purposes of presenting costs of equipment and operation is given in Fig. 61.

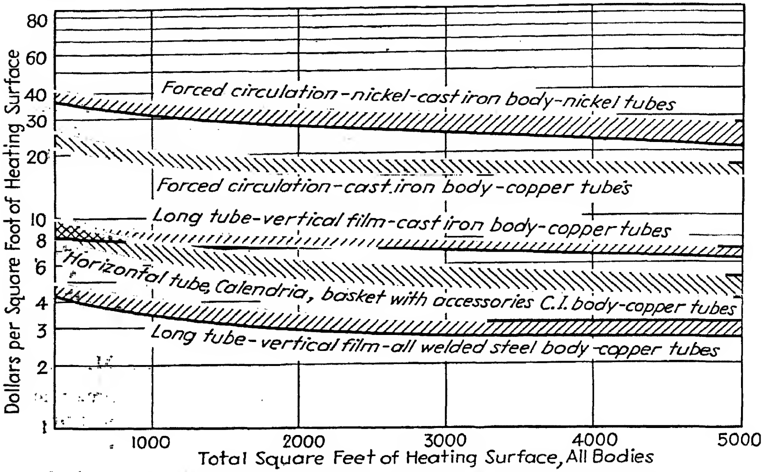

FIG. 61.—Cost of evaporator bodies. Cost is expressed in dollars per square foot of heating surface. (*Courtesy of Swenson Evaporator Company, Harvey, Ill.*)

Evaporator costs per square foot of heating surface (Badger in Perry's Handbook, p. 1047).

Vertical tube, 50 to 5,000 sq. ft.	$17 to $4
Horizontal tube, 50 to 2,300 sq. ft.	$18 to $4
Forced circulation, 50 to 2,500 sq. ft.	$72 to $4

Auxiliary equipment for evaporators:

Condensers for large multiple effects	5 per cent of base cost
Condensers for small installations	20 per cent of base cost
Vacuum pumps	20 per cent of base cost
Salt catches	10 per cent of base cost

Special materials of construction (iron for basic construction)

Tubes, copper instead of iron, add	10 per cent to base price
Steel body and tubes, deduct	20 per cent from base price
Lead tubes and lead-lined body, add	150 per cent to base price

c. Condensers.

Condensers vary considerably in cost depending upon materials of construction and service. A floating-end, 24-in. diameter condenser, with capacity between 200 and 300 gal. cooling water per minute, costs approximately $300 while a 100-in. size with capacity between 6,000 and 9,000 gal. per minute costs ten times as much. A Tulsa type with 24 sq. ft. of cooling surface costs approximately $125. A 2,000 sq. ft. condenser with admiralty tubing approximates $2.75 per sq. ft. (see Fig. 62).

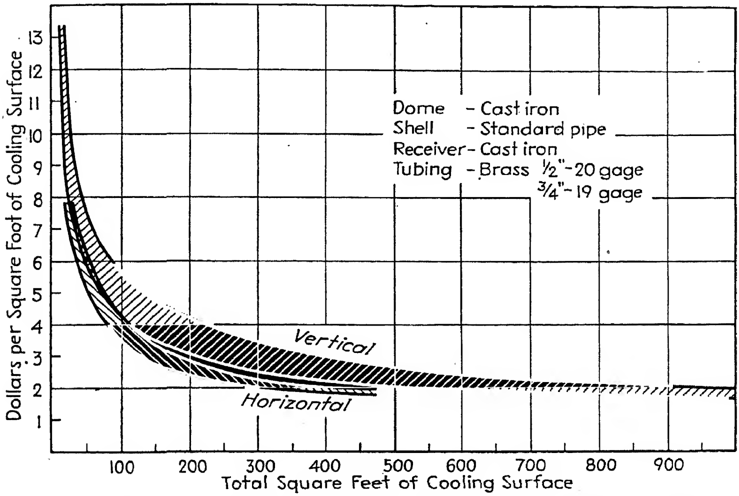

FIG. 62.—Cast or unit surface condensers. (*Courtesy of J. P. Devine Company, Mt. Vernon, Ill.*)

d. Crystallizers.

Swenson-Walker	$65 to $75 per foot of length
Batch coil, 1,000 gal	$500

e. Distillation.

Distilling equipment, 1,000 gal. alcohol per hour, $47,000.

Batchstill, aluminum (jacketed) 350 gal. capacity................ $580

36-plate, bubble-cap, low-pressure, steel; 30 in. diameter by 42 ft. high, $2,500.

9-plate, bubble-cap, single 6 in.; 12 in. diameter by 10 ft. high, $600.

TABLE 92.—DISTILLATION COLUMN COSTS[1]

Plate spacing, inches	Allowable velocity, ft. per sec.	Efficiency,	Number of plates	Column diameter, inches	Cost of column, dollars
6	1.35	0.98	20	42.00	1,095
7			20	42.00	1,106
11			20	18.00	397
11			20	44.00	1,341
12	3.10	0.98	20	27.75	645
15			20	42.00	1,310
18	4.50	0.98	20	23.00	680

[1] PEAVY, C. C., and E. M. BAKER, The Efficiency and Capacity of a Bubble Plate Fractionating Column, *Trans. Am. Inst. Chem. Engrs.*, **33**, 341 (1937).

f. Dryer.

Rotary, steel, 6 ft. by 26 ft. 8 in., for drying corn germ; containing 48 4½-in. 10-gage steam-heated tubes; direct motor drive, 5 hp	$ 8,000
Rotary, steam-jacketed meal dryer, ribbon-screw agitated, 30 bu. per hour capacity	675
Distillery feed pressing and drying equipment	12,000
Spray dryer, gasoline solvent from rosin	5,000

See Fig. 63 for cost of vacuum chamber dryers.

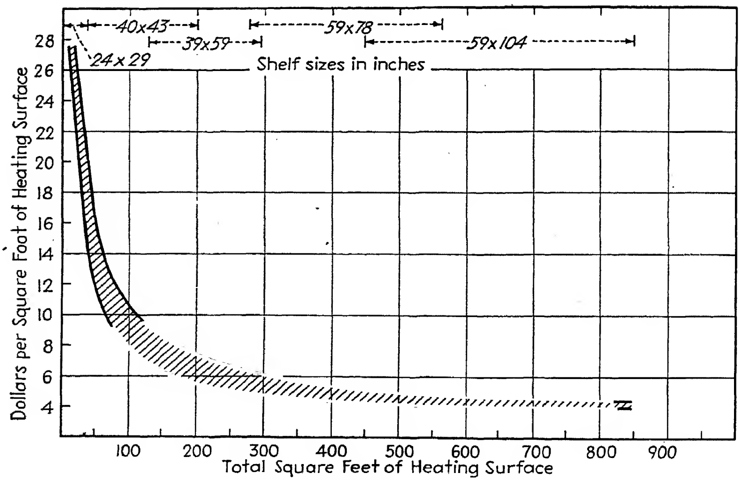

FIG. 63.—Cost of vacuum chamber dryers. (*Courtesy of J. P. Devine Company, Mt. Vernon, Ill.*)

TABLE 93.—COMPARATIVE COSTS OF YARD AND KILN DRYING

	Kiln drying			Yard drying		
	High	Medium	Low	High	Medium	Low
Transportation (lab., maint., int., and dep.)	$0.40	$0.20	$0.10	$0.60	$0.30	$0.20
Piling	0.50	0.35	0.20	0.50	0.45	0.35
Unpiling	0.35	0.25	0.16	0.40	0.30	0.20
Supplies—stickers and pile covers	0.06	0.04	0.02	0.06	0.04	0.02
Repairs	0.20	0.08	0.04	0.08	0.02	0.01
Steam (lab., main., int., and dep.)	0.45	0.30	0.25			
Supervision	0.20	0.10	0.06	0.12	0.06	0.04
Interest on investment	0.30	0.25	0.20	0.05	0.03	0.02
Depreciation (on kilns)	0.25	0.20	0.15			
Interest on stock (drying)	0.05	0.03	0.02	1.50	1.25	1.00
Fire insurance	0.25	0.18	0.15	0.75	0.60	0.50
Loss by drying defects	1.00	0.50	0.25	3.50	2.00	1.25
Totals	$4.01	$2.48	$1.60	$7.56	$5.05	$3.59
Savings	3.55	2.57	1.99			

NOTE.—The above ranges in cost vary with the quantity of lumber involved, and method of handling and transporting, grades and values of stock, and similar factors. It is not likely that all items would be either high or low at any one plant. Care in the operation of the kiln, the kind of kiln used, the climatic conditions, and the species of wood are important items.

TABLE 94.—COST OF HEAT AND COAL FOR DRYING GRANULAR SOLIDS

To drive off moisture (theoretical) per ton (2,000 lb.) of dry material

Moisture, per cent	Water, pounds	At 100 per cent efficiency		Moisture, per cent	Water, pounds	At 100 per cent efficiency	
		Total B.t.u.	Coal, pounds			Total B.t.u.	Coal, pounds
1	20	86,200	7.2	25	667	809,550	67.5
2	41	109,680	9.2	30	857	1,021,970	85
4	83	156,530	13.1	35	1,077	1,267,930	106
6	128	207,940	17.7	40	1,333	1,554,130	130
8	174	258,370	21.5	50	2,000	2,299,840	193
10	222	312,040	26.0	60	3,000	3,417,340	285
12	273	369,050	30.8	70	4,667	5,280,430	440
14	325	427,190	35.6	80	8,000	9,000,840	756
16	381	489,800	40.8	85	13,333	12,734,090	1,060
18	439	554,640	46.2	90	18,000	20,188,000	1,680
20	500	622,840	52	95	38,000	42,548,000	3,550

NOTE.—Total B.t.u. include 63,840 B.t.u. to raise temperature of material from 60° to 212°F., at which point evaporation takes place (sea level); specific heat of material taken as 0.21. Coal assumed to have 12,000 B.t.u. per pound as used and is for 100 per cent efficiency as specified. Table of coal added to original data by General Engineering Company.

Rotary dryers have efficiencies of 50 to 70 per cent; coal consumption may be determined from the above table by subtracting pounds of coal corresponding to percentage of moisture in the dried product from the pounds of coal to percentage of moisture in the feed, and dividing by the efficiency expressed decimally. Power required for mechanism and fan is about 1 hp. per ton of moisture removed per 24 hr. Capacity 250 to 660 lb. water evaporated per square foot section per 24 hr.

6. STORAGE AND PROCESSING

a. Vats.

Redwood, round vat, straight sides, 3-in. staves, 14 by 15 ft. 4 in., 17,000 gal.	$ 500
Redwood, as above, except 2-in. staves, 8 by 5 ft. 5 in.	200
Fermentation tanks, redwood, 18,000 gal.	800
Concrete tanks, reinforced, 10 by 10 by 14 ft., with 14-in. wall.	650
Concrete tanks, reinforced, 14 by 14 by 14 ft., with 18-in. wall.	820

b. Tanks.

Chemical stoneware, 11 by 9 by 8 in.	14
42 by 20 by 12 in.	92
Steel, round, 12 by 15 ft.	480
12 by 7 ft. 8 in.	420
8 by 8 ft.	360
8 by 6 ft.	280
6 by 6 ft.	90
4 by 5 ft.	30
Steel, cylindrical, 100-lb. test, 30,000 gal. capacity	1,500
Nickel, 600 gal. 5 by 4 ft. open, flat bottom	350
150 gal. 3 by 3 ft. open, flat bottom	165
30 gal. 15 by 2 ft. open, flat bottom	85
750 gal. 5 by 4.5 ft. open, conical bottom	503
500 gal. 4 by 5 ft. open, conical bottom	345
1000 gal. 5 by 9 ft. closed vacuum 500 gal. liquor capacity	3,083
500 gal. 4 by 5 ft. closed, vacuum, (nickel clad steel) 26 in. vacuum	735

See Fig. 64 for approximate costs of wooden tanks.

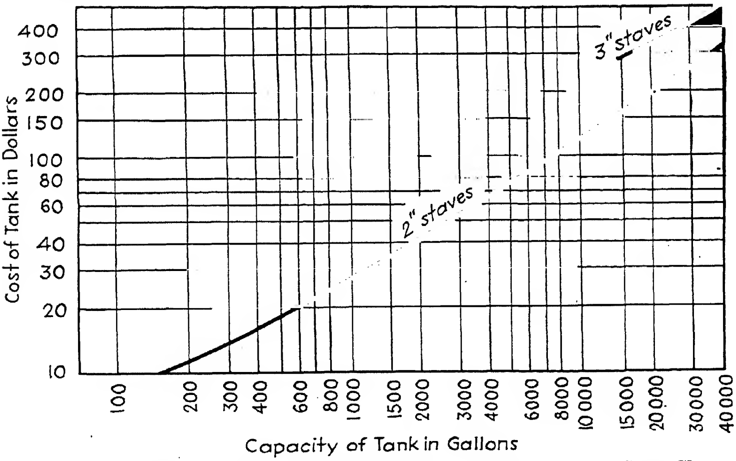

FIG. 64.—Approximate costs of wooden tanks. [*C. S. Robinson, Ind. Eng. Chem.* **14**, 604 (1922).]

c. Barrels.

Steel, 10 gal., each	$ 2.20

d. Water Towers.

200,000-gal. capacity, three-panel, six-column, 92-ft. tank (installed)	$16,000
10,000-gal. capacity, four-column 75-ft. tank (installed)	5,000

7. Wells

Deep drilled, 1,000 gal. per minute, 8-in. casing, limestone region	$ 5,000
Shallow, bored in alluvial soil, 100 ft. deep, 20 in. diameter	4,500

8. Steam Plant

Approximately $17 per boiler horsepower.

Table 95.—Analysis of Costs for Industrial Boiler Plant[1]

	Dollars per 100 Sq. Ft. of Boiler Surface
Foundations for building equipment	8–12
Building and fuel bunkers	20–40
Boiler, superheaters, soot blowers, etc. (less than 250 lb.)	20–35
Economizers (erected)	10–20
Air heaters (erected)	10–15
Settings	6–10
Coal firing and forced-draft equipment	12–18
Coal handling equipment	5–7
Ash handling equipment	4–5
Breeching and chimney	7–10
Feed pump	2–3
Piping	10–5
Water treating plant	6–9
Motors, wiring and lighting	6–8
Combustion control	1–3

[1] Bleibtrey, H., *Power*, Oct. 6, 1931.

9. Motors

Table —Motor Costs (Not Installed)

Horse power	Equipment	Cost
3	Complete	$130
10[1]	Motor only	$136–$ 785
10[1]	With control	175– 815
20[1]	Motor only	200– 1,075
20[1]	With control	275– 1,095
50[1]	Motor only	360– 1,955
50[1]	With control	415– 2,050

[1] Compiled from Perry's "Chemical Engineers' Handbook," 2d ed., p. 2719.

Squirrel-cage induction motors decrease perceptibly in cost per horsepower, the ½-hp. motors approximating $68 per horse-

power; on the same basis, a 1-hp. motor would cost $44, a 10-hp. around $12.90 and a 40-hp. approximately $7.80 per horsepower.

10. Pumps

Table 97.—Pump Costs

Type	Drive	Capacity, gal. per min.	Head, ft.	Cost range
Centrifugal, single-stage..........	Motor	35 – 250	10	$ 25– 100
Centrifugal, single-stage..........	Belt	10 –2,070	10–30	25– 250
Centrifugal, two-stage...........	Motor	50 –8,000	25–480	225–1,000
Reciprocating, duplex...........	Belt	30 – 450		300–1,100
Reciprocating, duplex, double-acting......................	Steam	14 – 170		100– 500
Reciprocating, triplex............	Belt	2¾– 220		90–1,000
Rotary.......................		4 – 850		75– 800

Table 98.—Capacities and Cost Range of Reciprocating Pumps

Type	Action	Drive	Use	Capacities, gal. per min.	Cost range, dollars
Simplex.	Direct	Steam	General	12 –360	125–1,000
Duplex..		Belt	General	30 –450	300–1,100
Duplex..	Direct	Steam	General	14 –170	100– 500
Duplex..	Direct	Steam	Low pressure	35 –295	130– 550
Triplex..	Direct	Steam	High pressure	2½–220	90–1,000

Variations of Costs Due to Different Materials of Construction. All-iron pumps are available, but parts such as shafts, linings, valves, pistons, etc., are often supplied with parts of other materials. The following comparative costs of standard pumps are based on iron pumps with bronze parts as 1.0; all iron, 0.9; acid-resisting bronze, 1.5–1.75; aluminum bronze, 2.0; Monel (parts) 3.0; Monel, 5.0; stainless steel 3.0–5.0; inconel, 5.0–7.0; hastelloy, 7.0–9.0; illium, 5.0–7.0.

11. Pumping and Piping

For comparing costs of pumping and piping in a given installation, for various pipe sizes, the pressure head is taken as constant

and need not be considered; also the velocity head may be neglected, since in the comparison only the differences in total head are considered. Pipe costs per pound will vary, but a table for comparison of economic data on pipe lines can be prepared, similar to that of Funder (Table 101), which is based on a cost of $0.06 per pound for erected pipe. Erected-pipe costs will vary with the difficulty of the layout, with size and material, and, for underground pipe, with the terrain and composition of the soil. Figure 65 is an excellent chart for determining the cost of pumping of 1,000 gal. of water.

TABLE 99.—COST ESTIMATES PER FOOT OF SCREW PIPE LINES

Size of line, inches Weight, pounds per foot	2 3.75	3 7.70	4 11.00	6 19.45	8 29.35	10 32.75
Screw pipe (new)	$0.1881	$0.3266	$0.4665	$0.8338	$1.3136	$1.6579
Paint at 75 cents per gallon	0.0038	0.0068	0.0089	0.0131	0.0169	0.0210
Ditching, painting, laying, and back-filling	0.12	0.14	0.17	0.24	0.30	0.41
Hauling and stringing 6 miles at 50 cents per ton-mile	0.0056	0.0116	0.0165	0.0292	0.0440	0.0482
Right of way and damages	0.0454	0.0454	0.0454	0.0454	0.0454	0.0454
Engineering and superintendence, 3.3 per cent	0.0120	0.0175	0.0233	0.0379	0.0568	0.0720
10 per cent overhead	0.0375	0.0548	0.0731	0.1188	0.1777	0.2255
Total cost, per foot	0.41	0.60	0.80	1.31	1.95	2.48

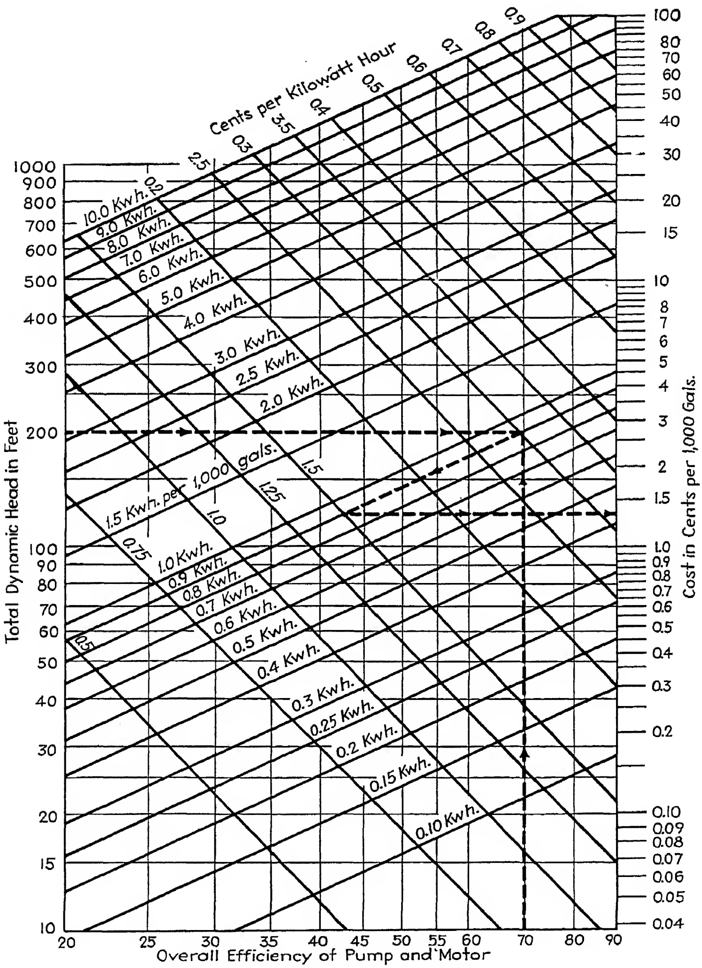

FIG. 65.—Cost of pumping 1,000 gal. The chart shown above is useful in obtaining the cost of pumping 1,000 gal. of water against a specified total dynamic head with a given over-all efficiency of pump and motor (including transformer, board losses, etc.). The capacity of the pump does not enter into the calculation. For identical efficiencies and power rates the cost of pumping 1,000 gal. is the same regardless of the time to pump. (*Courtesy of Economy Pumps, Inc., Hamilton, Ohio.*)

TABLE 100.—PRICE LIST ON LABOR ON PIPE BENDING, CUTTING, WELDING AND THREADING
(Standard black or galvanized)

Pipe size, inches	Price per foot	Butt welding 150-lb. grade	Cutting plain ends per end	Threading straight pipe per end	Cutting and threading of pipe bends per end	Bending of pipe with plain ends				
						Quarter and angle	U-bend	Single offset quarter bend	Expansion U-bend	Double offset U-bend
1/8, 1/4	0.06	2.50	0.06	0.05	0.21					
3/8										
1/2	0.085	2.50	0.06	0.05	0.21					
3/4	0.115	2.50	0.06	0.05	0.21					
1	0.17	2.50	0.08	0.06	0.28	9.75	11.50	18.50	24.50	34.00
1 1/4	0.23	2.75	0.08	0.07	0.28	11.00	13.25	21.25	28.00	35.00
1 1/2	0.275	2.75	0.09	0.08	0.32	12.00	15.50	24.00	32.00	41.00
2	0.37	3.50	0.10	0.10	0.32	14.50	19.25	28.00	38.00	46.00
2 1/2	0.585	4.50	0.12	0.15	0.42	15.75	22.50	32.00	42.00	52.00
3	0.765	5.50	0.17	0.20	0.65	17.00	25.50	35.00	47.00	59.00
3 1/2	0.92	6.25	0.20	0.25	0.75	23.50	29.00	43.00	57.00	67.00
4	1.09	7.25	0.30	0.35	1.05	25.00	35.00	48.00	64.00	77.00
5	1.48	9.25	0.45	0.55	1.60	33.00	42.00	59.00	79.00	91.00
6	1.92	11.00	0.55	0.70	1.85	40.00	49.00	69.00	92.00	137.00
8	2.50	14.60	0.75	1.00	2.65	53.00	70.00	95.00	137.00	164.00
10	3.50	18.25	1.25	1.50	4.00	70.00	97.00	126.00	186.00	223.00
12	4.50	23.00	2.00	2.50	6.60	95.00	125.00	165.00	263.00	373.00

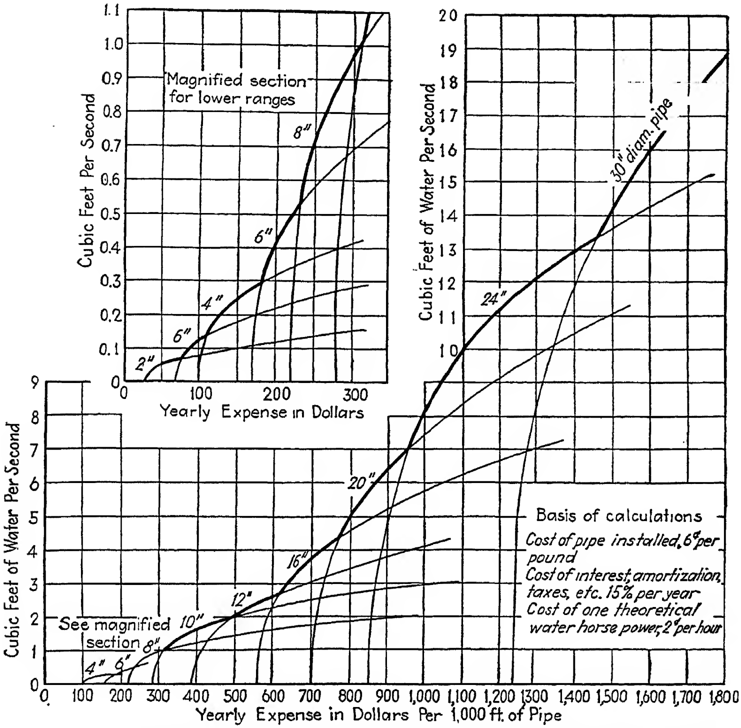

FIG. 66.—Total yearly costs of various pipe sizes, per 1,000 ft., at various flow rates, showing economical range for each size. [*Funder, Chem. Met. Eng.*, **39**, 602 (1932).]

TABLE 101.—ECONOMIC DATA ON PIPE-LINE COSTS[1]
(Basis: Erected pipe, $0.06 per pound, power at switchboard, $0.01 per kilowatt-hour; cost of one theoretical water horsepower, $0.02 per hour)

Diameter of pipe, inches	3	6	12
Cost of 1,000 ft. of pipe	$450	$1,140	$2,620
Fixed charges, 15 per cent per year	$ 68	$ 170	390
Economic flow, cu. ft. per sec	0.1	0.45	2.2
Velocity, ft. per sec	2.0	2.3	2.8
Friction loss, feet head per 1,000 ft	8.0	5.5	3.0
Yearly power costs	$ 17	$ 30	130
Total yearly costs	$ 85	$ 200	520
Total yearly cost for 1 cu. ft. per sec.	$850	$ 444	236

[1] FUNDER, M., *Chem. Met. Eng.*, **39**, 602 (1932).

Funder (*loc.cit.*) has also drawn graphs showing the economic range for each size of pipe. These are given in Fig. 66.

D. INSTALLATION COSTS

TABLE 102.—COST OF ERECTION[1]
(Cost of labor only in erecting machinery; based upon invoice cost)

	Per cent		Per cent
Beaters	25	Mills	
Blowers	5–10	1. Ball, rod, pebble	4–10
Boilers	40–50	2. Roller	15–20
Classifiers	3–5	3. Hammer	20
Compressors	3–7	Motors	6–20
Conveyors	20–25	Pumps	
Dryers	20–30	1. Centrifugal	8–15
Elevators (bucket)	25–40	2. Duplex	20
Evaporators	25	3. Triplex	6
Feeders	5–10	4. Vacuum	3–7
Filters		Roasters	12
1. Filter presses	25–30	Rolls	4–12
2. Pressure leaf	25	Scales (platform)	40
3. Vacuum continuous	25	Screens	5–15
Flotation machines	5–8	Tables	10–12
Gyratory crushers	5–13	Tanks (wood)	12–20
Jaw crushers	8–10	Thickeners	12–15
Jigs	12–15	Vats (circular, redwood)	25–30
		Wagon unloader	35

[1] Taken from a variety of sources.

TABLE 103.—LABOR ERECTING MEDIUM-SPEED MOTORS[1]

Horse power	Cost of erecting motors ($7 per day)		Time for erecting motors			
	Floor	Ceiling	Floor		Ceiling	
			Hr.	Min.	Hr.	Min.
1–3	$ 3.50	$ 7	4	0	8	0
5	5	10	5	43	11	25
7.5	7	11	8	0	12	34
10	8	12	9	06	13	42
15	10	15	11	25	17	08
20	12	20	13	42	22	50
25	14	25	16	0	28	33
30	18	30	20	34	34	16
40	21	45	24	00	51	23
50	24	60	27	25	68	32
75	35	...	40	0		
100	40	...	45	40		
125	50	...	57	06		
150	60	...	68	32		

NOTE.—Add extra labor for motor supports; also for hoisting above ground floor; add 50 per cent extra labor for slip-ring motors with simple starters.

[1] Values based on ground-floor handling; motors handled without special equipment.

E. POWER-COST DATA

TABLE 104.—HORSEPOWER TO OPERATE EQUIPMENT

Whirlbeater, 100 cwt. corn per hour	60
Attrition mill, 100 cwt. corn per hour	30
Pebble mill, 1.75 tons feldspar per hour	88
Ball mill, 26 tons limestone per hour	48
Ball mill, 50 tons barytes per hour	125
Pulverizer, 5.5 tons bituminous coal per hour	140
Rotary driers, per ton moisture removed	1
Filter press, per square foot filter area	0.005
Pressure leaf filter, per square foot filter area	0.020
Vacuum continuous filter, per square foot filter area	0.050

MECHANICAL HANDLING EQUIPMENT POWER REQUIREMENT FORMULAS

$$\text{Belt conveyors } \frac{L(0.00009w^2V + 0.08W) + WH}{1{,}000}$$

$$\text{Roller flight conveyors } \frac{0.78WL + WH}{1{,}000}$$

Shoe flight conveyors $\dfrac{0.933WL + WH}{1,000}$

Screw conveyors $\dfrac{0.68WL + WH}{1,000}$

Bucket elevators $\dfrac{1.5WH}{1,000}$

Bucket pivoted carriers $\dfrac{(0.28L + 1.08H)W + 90W}{1,000}$

where w = width of belt.
V = speed in feet per minute.
W = load handled in tons per hour.
L = total length in feet.
H = rise in elevation in feet.

TABLE 105.—COST OF ELECTRIC POWER
(Based on reported costs of power in milling plants)

Cost per hp.-year	Cost per hp.-month	Cost per kw.-hr.	Conditions
$150	$12.50	2.0 cts.	Unfavorable
120	10.00	1.6	Unfavorable
90	7.50	1.2	Unfavorable
75	6.25	1.0	Average
60	5.00	0.8	Average
45	3.75	0.6	Favorable
30	2.50	0.4	Favorable

NOTE.—These figures are for 360 twenty-four-hr. days per year, and an average motor efficiency of 85 to 88 per cent.

Mantell, in Perry's "Chemical Engineers' Handbook," 2d ed., p. 2801, portrays a graph showing comparative costs of industrial fuels.

F. OPERATING LABOR COSTS

The cost of operation of equipment varies with the equipment. Some sorts of equipment require more skill, operators of better technical training and more technical supervision than others. Engineering experience must be relied on to furnish most of this information, but there are also available data on chemical engineering unit-operation equipment labor costs, such as for evaporators, filters, driers and grinding equipment. The number of men and the number of shifts must be considered as a whole. The actual number and type of operators, supervisors, repair men, etc., must be determined from the operation instructions for the plant.

Labor and Management.—When determining labor and management cost, local conditions will prevail, but some average must be obtained. A request to the local chamber of commerce will generally yield data on prevailing rates. Chemical engineering plants do not employ many men in comparison with most industries. Data on labor and management costs oftentimes must be obtained from the engineer's experience. In general, industry in America can always expect higher labor costs.[1]

TABLE 106.—MEN EQUIVALENCY
Men per unit

	Men		Men
Whirlbeaters	1	Vacuum continuous filters	$\frac{1}{5}$
Attrition mills	1	Evaporators	1
Pebble mills	1	Belt conveyors	$\frac{1}{4}$
Ball mills	$\frac{1}{5}$	Flight conveyors	$\frac{1}{2}$
Unit pulverizers	$\frac{1}{4}$	Screw conveyors	$\frac{1}{2}$
Filter presses	2	Bucket elevators	1
Pressure leaf filters	$\frac{1}{2}$	Bucket carriers	1
Suction conveyors			

G. MAINTENANCE AND SUPPLIES

TABLE 107.—ANNUAL COST OF MAINTENANCE

	Per Cent[1]
Kettles, Monel metal (varnish)	7
Kettles, copper (varnish)	50
Filter presses (cloth, 1 month)	5
Pressure leaf filters (cloth, 3 months)	4
Vacuum continuous filters (cloth, 24 months)	4
Evaporators	5
Belt conveyors	4
Flight conveyors	15
Screw conveyors	15
Bucket elevators	15
Bucket carriers	15
Suction conveyors	10
Pipe lines	1
Whirlbeaters	3
Attrition mills	25
Pebble mills	25
Ball mills	20
Unit pulverizers	10

[1] Per cent of first cost.

[1] RISING, F., *Chem. Met. Eng.*, **45, 72** (1938).

H. GENERAL REPAIRS

TABLE 108.—COST OF EQUIPMENT REPAIRS

	Per cent[1]		Per cent[1]
Whirlbeaters	1	Evaporators	1
Attrition mills	1	Belt conveyors	1
Pebble mills	3	Flight conveyors	5
Ball mills	1	Screw conveyors	5
Unit pulverizers	2	Bucket elevators	5
Filter presses	3	Bucket carriers	5
Pressure leaf filters	1	Suction conveyors	5
Vacuum continuous filters	1	Pipe lines	1

[1] Cost per year, percentage of first cost.

I. MANAGEMENT AND MARKETING

TABLE 109.—ESTIMATED PRODUCTION AND DISTRIBUTION COSTS[1]
(Per cent of selling price)

Industry	Production	Distribution, including overhead	Profit	Selling expense
Typical chemical product	65	14	9	12
Chemical engineering equipment	73	8	5	14
Food-products industry	62	9	5	24
All industries	61	16	10	13

[1] Based on *Chem. Met. Eng.*, **39**, 4–5 (1932).

TABLE 110.—ESTIMATED DISTRIBUTION OF FACTORY COSTS[1]
(Per cent of total factory cost)

Product	Raw materials	Labor	Fuel, power and water	Repairs and maintenance	Depreciation	Miscellaneous
Cotton cloth	34.9	38.5	6.2	3.6	5.0	11.8
Mixed fertilizer	63.4	12.2	6.0	8.0	8.0	2.4
Window glass	23.7	33.5	12.8	10.8	13.2	6.0
Outside paint	75.0	10.0	3.6	5.0	5.0	1.4
Rayon yarn	26.4	40.3	13.0	4.9	8.0	7.4
Rubber tires	49.1	30.0	6.9	6.0	5.0	3.0
Soap	62.1	8.5	1.9	7.5	10.0	10.0
Sugar	88.3	5.1	2.2	3.1	1.3	

[1] Based on *Chem. Met. Eng.*, **39**, 6–7 (1932).

TABLE 111.—DISTRIBUTION OF CHEMICAL PLANT COSTS[1]
(Per cent of selling price)

Product	Raw materials	Direct labor	Fuel, power, water	Repairs and maintenance	Depreciation	Miscellaneous, royalties, factory administration, fixed charges	Taxes and insurance	Distribution and profits
Acids								
Acetic	55.1	2.6	1.9	1.1	0.3	6.9	0.7	32.1
Nitric (retort)	70.0*	2.5	1.2	5.0	5.0	2.7	3.6	24.0
Nitric (NH_3 oxid.)	20.6	5.0	4.0	2.0	3.0	12.0	3.0	50.0
Sulfuric (chamber)	52.3	4.8	2.6	2.9	5.0	3.5	2.1	26.8
Sulfuric (contact)	50.6	4.8	3.8	3.7	5.0	3.5	2.1	26.5
Alcohol								
(denatured, from molasses)	44.0	2.0	10.0	4.0	8.0	4.0	4.0	22.0
Aluminum sulfate	43.3	5.3	6.5	2.9	3.4	10.8	1.3	26.5
Carbon black	22.4	2.0	10.9	2.0	24.8	3.0	3.0	31.9
Potassium permanganate	35.2	9.7	13.5	3.2	2.6	3.8	1.3	30.7
Sodium salts								
Soda ash	24.4	4.0	10.3	6.8	15.2	4.3	2.6	32.4
Caustic soda (lime)	37.4	5.7	8.2	3.9	5.7	3.0	2.0	34.1
Caustic soda (electrolytic)†	21.6	23.8	45.2	14.3	11.0	10.4	2.4	35.6
Trisodium phosphate	44.7	5.0	5.9	2.5	5.0	5.0	2.4	29.5
Ultramarine blue	20.8	23.3	7.2	7.7	4.5	4.8	2.3	29.4
All industries	21.0	19.6	2.7	2.7	5.0	15.0	2.5	31.5

[1] Based on *Chem. Met. Eng.*, **39**, 2–3 (1932).

* Credit of 14 per cent for nitre cake.

† Credit of 64.3 per cent for chlorine.

TABLE 112.—DISTRIBUTION OF SELLING, GENERAL AND ADMINISTRATION COSTS[1]
(Based on costs of a large chemical company)

Component	Selling expenses, per cent	General and administrative costs, per cent
Advertising	9.5	
Brokerage and storage	7.3	
Building and office operation	7.4	8.6
Contributions and pensions	....	14.8
Freight equalization	31.8	
Insurance and taxes	1.4	13.8
Legal department	....	3.2
Trucking	7.9	
Salaries	34.7	59.1
Others	....	0.5

[1] *Chem. Met. Eng.*, **39**, 4–5 (1932).

J. CAPITAL COSTS

A single-process plant is a unity and can be treated as such in cost accounting; but generally in multiprocess plants no single plant process could operate economically if it were to shoulder the entire burden of a steam power plant, a personnel such as timekeepers, clerks, watchmen, stores, general laborers, mechanics, control chemists, superintendent, general manager, office help, treasurer, secretary, president and like overhead. Nor is it reasonable not to expect other products to bear their proportionate share of an overhead expense, except in special cases, as when a product is newly developed, or when its disposal at a loss is necessary to avoid a nuisance. Consequently, proration of such expense is necessary, and the proper distribution (which, however, is often inexact) becomes a problem for the accountant of the plant. The engineer should obtain the data for his estimates from the proper offices in this case.

Rental, insurance and taxes are fixed charges that are also included in preconstruction cost accounting; rental data are easily available and the insurance and taxes can readily be estimated. Based upon 90 per cent of valuation of installed investment, the insurance item varies between 0.1 per cent on fireproof, sprinkler-protected buildings, to 1½ per cent on

highly flammable buildings in which flammables are stored. Insurance provides industries with a factor of safety.[1] Taxes vary with the community in which the plant is to be erected. Taxation basis is 60 per cent of the valuation. They may amount to as much as 2 per cent of the total capitalization of the plant. An item of social security insurance of 1½ per cent of the wages paid all employees earning less than $2,500 per year must be added to the fixed charges.

Plant Investment.—In determining what amount of money will be required for a new plant, it is not sufficient to consider the outlay for buildings and equipment alone. In addition, money must be available to cover all costs of operation, raw materials and overhead expense, for a period generally taken as one year. This latter quantity is known as the *working capital.* Since money for working capital is generally tied up as tightly as the actual investment, it is usually considered as part of the investment.

Interest on Investment.—Interest on the investment, at 6 per cent, is sometimes considered an element of operating cost. However, it cannot be so charged for income tax purposes, nor is it generally considered as operating expense by accountants. Although the question is debatable, it appears that the best opinion permits the use of interest on investment as a cost only when comparing the returns from two different investments, as, for example, two different processes for making the same or different products.

K. DEPRECIATION

Depreciation is the unavoidable loss in value of plant, equipment and materials with lapse in time, caused by:

A. Chemical action or corrosion.
B. Physical action.
  1. Decay.
  2. Decrepitude.
  3. Abrasion.
  4. Normal wear.
  5. Deferred maintenance or repair.

C. Inadequacy.
D. Obsolescence.

[1] Stratton, R. C., *Chem. Met. Eng.*, **45**, 74 (1938).

Various methods of calculating depreciation have been proposed, among them (1) the "straight-line method,"[1] (2) percentage on diminishing value, and (3) the sinking-fund method. For a chemical plant as a whole, a figure of 5 per cent is often considered as fair.

TABLE 113.—PROBABLE DEPRECIATION RATES FOR CHEMICAL PROCESS EQUIPMENT

Source: U. S. Bureau of Internal Revenue

	Depreciation Rate, Per Cent
Acids:	
Acetic:	
Blow cases, cast iron and copper	33⅓
Columns, fractionating	12½
Condensers:	
Copper	10
Duriron	7
Lead	16⅔
Motors	7
Pipes:	
Aluminum	33⅓
Glass	20
Acid:	
Copper	10
Rubber	12½
Water	10
Pots	6
Pumps, vacuum	14
Receivers, acid (stoneware)	7
Scrubbers (stoneware)	7
Receivers, acid, for product (stoneware)	5
Stills:	
Cast iron	8
Refining, copper	7
Refining, heating coil	33⅓
Tanks, storage:	
Steel	8
Wood	4
Muriatic:	
Air lifts (hard rubber)	10
Cars, tanks	10
Coolers	10
Elevators, bucket	10
Exhausters (rubber lined)	12½
Flues (earthenware)	10
Furnaces, Mannheim	12½
Furnaces, pot and muffle	10
Furnaces, retort	12½
Grinders and coolers, salt cake	8⅓
Motors	7
Pipes:	
Acid (hard rubber)	14
Chemical ware	50
Oil	5
Water	25
Pots, condensing (earthenware)	14
Pumps and blowcases:	
Chemical ware lined	33⅓
Rubber-lined blowcase	20
Storage tanks (wooden, rubber lined)	7
Tanks, sulfuric-acid storage (steel)	5
Tourills (silica)	10
Towers, absorbing	10
Nitric:	
Blowers (stoneware)	20

[1] TYLER, CHAPLIN, "Chemical Engineering Economics," 2d ed., p. 206, McGraw-Hill Book Company, Inc., New York, 1938.

TABLE 113.—PROBABLE DEPRECIATION RATES FOR CHEMICAL PROCESS EQUIPMENT.—(*Continued*)

	Depreciation Rate, Per Cent
Blow cases (earthenware)	50
Condensers (Duriron)	8⅓
Condensers, S bend (stoneware)	40
Elevators and conveyors (screw)	10
Flues, gas (Duriron)	12½
Pans, niter cake (steel)	7
Pipes and fittings (earthenware duriron, lead)	50
Pumps, sulfuric (iron), centrifugal	20
Receivers (stoneware)	20
Retorts, 24-hr. service	40
Tanks (steel)	10
Towers, condensing	11
Sulfuric (chamber):	
Air lifts, acid	10
Blowers, gas (lead)	6
Blowcases	10
Chambers	6
Coolers, acid (lead coil), for salt water	10
Fans (cast iron)	10
Pipes (lead)	10
Pots, niter	5
Pumps, acid	20
Tanks (steel), acid storage, average weak and strong acid	5
Tanks, tower, acid distributing	12½
Towers, Gay Lussac	5
Towers, Glover	5
Sulfuric (contact):	
Air lifts	7
Blowcases (cast iron and steel)	20
Blowers:	
Connersville	14
Sturtevant	6
Burners:	
Brimstone	10
Glens Falls	10
Herreshoff	6⅔
Wedge, salt-water cooled	6⅔
Wylde	7
Coke boxes	6
Combustion chambers, brimstone	10
Compressors, air	6⅔
Contact mass, including plates and supports	6
Converters	7
Conveyors and elevators	10
Coolers:	
Drying acid	10
Gas	7
Gas, tower	10
Product	16⅔
Dust chambers (brick)	7
Filters, preliminary	9
Flues (iron)	7½
Gages, meters, pyrometers	7
Heaters, preliminary	7
Melters, brimstone	10
Motors	6
Pipes, acid	10
Platinum, in catalyst	2
Pumps, acid (iron)	14
Pumps, acid (lead)	12½
Separators	7
Sublimers, brimstone	10
Tanks:	
Roasted ore storage (steel)	5
Storage (lead)	5
Storage (steel)	6
Tank cars (steel)	8
Towers:	
Absorbing	11

TABLE 113.—PROBABLE DEPRECIATION RATES FOR CHEMICAL PROCESS EQUIPMENT.—(*Continued*)

	Depreciation Rate, Per Cent
Cooler, cold scrub	8[illegible]
Dry	10
Oleum	10
Scrub	10
Transferrers	11
Pulp and Paper and Paper Board	
Absorbing system, milk of lime	10
Barkers: drum	10
Hand	6⅔
Beaters	5
Bins, storage, chip	3⅓
Bleachers	6⅔
Burners, sulfur, acid plant	8⅓
Calenders	4½
Chippers	5
Conveyors: inside	6⅔
Outside	8⅓
Cookers	5
Coolers	10
Cutters	5
Cylinder machines, for paper and paper board	5
Deckers	5
Diffusers	4
Digester linings	14
Digesters:	
Indirect	4½
Rotary	5
Vertical, stationary	4
Drainers	3⅓
Evaporators:	
Disk	6
Multiple effect	4
Fourdrinier machines	5
Furnaces, rotary	6
Grinders	5
Jordans	5½
Knotters	6⅔
Kollergangs	5
Linings (wool) for blow pits	12½
Melters, sulfur	12½
Pans:	
Causticizing	6⅔
Wash	4
Pits, blow:	
Concrete	3⅓
Steel tank	5
Platers	7½
Pumps:	
Acid	20
Centrifugal	6⅔
Plunger, duplex or triplex	5½
Pressure	6⅔
Vacuum	6⅔
Reels	6⅔
Rifflers:	
Concrete	3⅓
Wood	5½
Save-alls	5
Screens:	
Silver	8
Rotary	6⅔
Shredders	8⅓
Slashers	7
Smelters, sulfate process	14
Stackers, pulpwood	7
Tanks:	
Causticizing	5
Leaching	4½
Mixing (wood)	8⅓
Mixing (wood) for clay	5
Storage, acid	8⅓
Storage or washing (concrete)	3⅓
Storage or washing (wood)	6⅔
Thickeners	5
Towers, absorbing system	6⅔
Washers, bleach or paper stock	5
Wet machines	5½
Rubber Goods	
Autoclaves	10
Boards, stock (wood)	25

TABLE 113.—PROBABLE DEPRECIATION RATES FOR CHEMICAL PROCESS EQUIPMENT.—(*Continued*)

	Depreciation Rate, Per Cent
Calenders	5½
Conveyors	6⅔
Covering machines	7½
Crackers, rubber	6⅔
Devulcanizers, reclaimed rubber	6⅔
Dipping machines	10
Disintegrators	6⅔
Drums	8⅓
Dryers	7
Dusting machines, including chalking	6⅔
Furnaces	6⅔
Grinders, pigment	6⅔
Mills, mixing or warming:	
Heavy duty	6
Light duty	6⅔
Mixers:	
Large	6
Small	6⅔
Ovens	6⅔
Presses, cold	5
Pulverizers	6⅔
Reeling machines	6⅔
Refiners, roll type	7
Rolling machines	6⅔
Sealing machines	7
Separators	7
Sheeters	6⅔
Sifters	7
Strainers	8⅓
Varnishing machines	6⅔
Vulcanizers	6⅔
Washers	6⅔
Winding machines	6⅔
Wrapping machines	8

Cement, Ceramics, Glass, Gypsum, and Lime and Limestone

	Depreciation Rate, Per Cent
Agitators	6⅔
Augers	7
Baggers	6⅔
Beaters, tub	6⅔
Blowers	6⅔
Blungers	8⅓
Bottle machines	10
Brickmaking machines	8
Burners	6⅔
Calciners, continuous	6⅔
Cars:	
Batch	8
Dryer or kiln	6⅔
Mine:	
Steel	10
Wood	20
Transfer	10
Casting and rolling tables	8
Charging machines	10
Controllers, temperature, automatic	10
Conveyors	6⅔
Coolers	7½
Crushers	6⅔
Cutoff machines	7
Cutting machines	7
Cutting machines, rock lath	5
Disintegrators	12½
Drag lines:	
Heavy	5
Light	10
Medium	6⅔
Dryers	9
Dryers, rotary	6⅔
Duster machines, bag	6⅔
Dust collectors	5
Elevators:	
Bucket	6⅔
Screw	5½
Feeders	8
Filter presses	6⅔
Furnaces	6⅔
Furnaces, pot	8
Grinders	6⅔
Hydrators	6⅔

TABLE 113.—PROBABLE DEPRECIATION RATES FOR CHEMICAL PROCESS EQUIPMENT.—(*Continued*)

	Depreciation Rate, Per Cent
Jigs	10
Kettles	6⅔
Kilns	6⅔
Lehrs	6⅔
Loading machines	10
Mills	6⅔
Mixers	7
Molds	20
Molds, hydraulic	8⅓
Mud machines	8
Ovens, flattening	8
Packers	10
Pallets and trays	12½
Pans, dry	6⅔
Plungers	10
Polishers	8
Presses	5
Pulverizers	6⅔
Pumps	6⅔
Pumps, clay	10
Reels	5
Riddles, gyratory	10
Scales:	
Platform	5
Portable	6⅔
Screens	10
Separators:	
Air	10
Magnetic	7
Shovels, electric or steam	6⅔

	Depreciation Rate, Per Cent
Sieves	12½
Sifters, revolving	10
Tables, drawing, grinding, or polishing	8
Tanks	5
Oil and Gas Refining	
Agitators	6¼
Carbon black plants	8
Condensers	6⅔
Exchangers, heat	6⅔
Filtering plants	5
Gasoline plants, natural gas	8
Pipes, interunit lines, small diameter	6⅔
Pumps	6⅔
Stills:	
Cracking	12½
Fire	6⅔
Steam	6⅔
Tube or pipe	8½
Vacuum	6⅔
Tanks:	
Compounding	5
Storage	5
Treating	6¼
Towers, scrubbing	6⅔
Traps, gas and water	8⅓
Wax plants	5

Although it is difficult to estimate service life and depreciation of equipment, engineers must make conservative estimates for large groups of items, and blanket estimation based upon judgment and experience is often as correct for large groups as carefully compiled rates. Kurtz[1] has presented an excellent treatise on the subject of depreciation and has given rather

[1] KURTZ, EDWIN B., "Life Expectancy of Physical Property," The Ronald Press Company, New York, 1930.

exhaustive data which can be used as a basis for engineering estimates on service life of most types of physical property.

Depreciation rates on factory buildings vary between 2 per cent for most types of masonry of slow-burning characteristics, to 3 per cent for masonry with frame interior, and 4 to 5 per cent for frame buildings. A classification of depreciation rates for chemical buildings and equipment is given in Table 113.

Time Unit.—The time unit is taken as a 300-day working year, with four 6-hr., three 8-hr., two 12-hr., one 10-hr. shift per day, or whatever the case demands.

Annual Costs.—The yearly costs are summarized by including (1) annual operating costs, (2) management and distribution expense, and (3) fixed charges. This figure then is the basis for determining the earnings of the company.

Gross Income.—On the basis of sales price, capacity and daily production, the gross income for 300 days, or the working year, is calculated.

Net Income.—The net income is determined by deducting the annual costs from the gross income.

TABLE 114.—SAMPLE PRECONSTRUCTION COSTS FOR FERROUS SULFATE RECOVERY PLANT

Raw Materials Costs

Ferrous sulfate liquor (waste)	$ 0.00
Scrap iron, 1,000 lb. per day at $0.005 per pound	5.00
Water, 73,000 gal. per day at $0.05 per 1,000 gal	3.65
Steam, 83,000 lb. per day at $0.40 per 1,000 lb	33.20
Electricity (power), 250 kw.-hr. per day at $0.02 per kilowatt-hour	5.00
(light), 30 kw.-hr. per day at $0.04 per kilowatt-hour	1.20
Total raw materials costs per day	$ 48.05
Total raw materials costs per 300 days	$14,415.00

Land and Building Costs

Land, 1 acre at $500 per acre	$ 500
Building, erected	17,500
Railroad siding	5,000
Excavation and foundations	1,737
Electric wiring and fixtures, installed	180
Office furniture	300
Runway, carpentry	312
Total	$25,539

TABLE 114.—SAMPLE PRECONSTRUCTION COSTS FOR FERROUS SULFATE RECOVERY PLANT.—(*Continued*)

Equipment Costs (Installed)

Reservoir and neutralizing tanks	$ 9,500
Filters and accessories	1,008
Evaporators and accessories	12,327
Crystallizers and accessories	4,686
Centrifugals and accessories	3,000
Dryer and accessories	4,435
Elevators, complete	659
Conveyors	181
Storage bin	1,430
Chemical lines and fittings	1,099
Steam lines and fittings	1,526
Water lines and fittings	521
Sewer layout and mother-liquor return	470
Power shafting and accessories	1,242
Motor and accessories	2,076
Freight	750
Total	$44,905

Cost of Labor and Supervision

	Salary per Day
1 plant manager at $3,000 per year	$ 10.00
6 operators at $1,800 per year	36.00
1 clerk	2.40
1 helper at $0.40 per hour	2.40
Total labor costs per day	$ 50.80
Total labor costs per year	$15,240.00

Fixed Charges

Taxes at 2½ per cent	$1,761
Insurance at ½ per cent	352
Depreciation at 5 per cent	3,522
Social security insurance at 1½ per cent	184
Total	$5,819

Working Capital

Raw materials costs	$ 14,415
Labor and supervision	15,240
Fixed charges	5,819
Incidentals, attorney's fees, etc	2,500
Total	$37,974

TABLE 114.—SAMPLE PRECONSTRUCTION COSTS FOR FERROUS SULFATE RECOVERY PLANT.—(*Continued*)

Capital Investment	
Land and building costs	\$ 25,539
Equipment costs	44,905
Working capital	37,974
Total	\$108,418
Gross Income	
Annual production of $FeSO_4.7H_2O$	6,630 tons
Annual value of product at \$14 per ton	\$ 92,820
Annual Costs	
Annual operating costs:	
Raw materials costs	\$14,415
Labor and supervision	15,240
Maintenance, 2 per cent	1,410
Fixed charges, management and distribution, 25 per cent on gross income	23,205
Total	\$54,270
Net Income	
Annual value of product	\$92,820
Annual costs	54,270
Net income	\$37,550

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CHAPTER XIII

LOCATING THE CHEMICAL PLANT

The best location for a chemical plant depends upon a number of factors, but the logical place is where the cost of production and distribution will be at a minimum, or where the aggregate

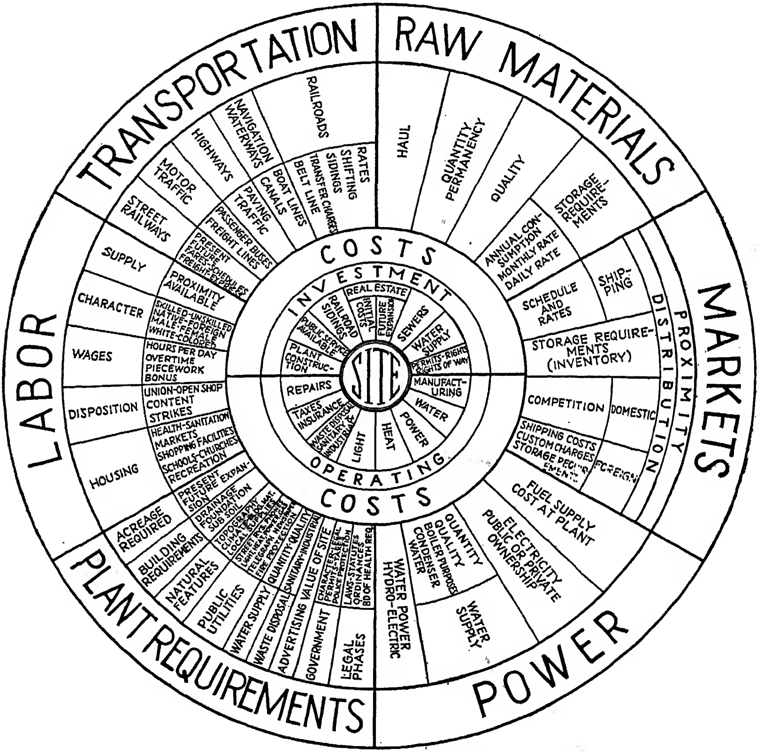

FIG. 67.—Influencing factors to be considered in the analysis of an industrial-plant location. [*Warner, J. L., Trans. Am. Inst. Chem. Eng.*, **32**, 143 (1936).]

cost of raw materials, transportation of materials to the plant, manufacturing, selling, and transportation of finished products to the market will be at a minimum. Location of a chemical

industry is determined by a careful analysis of all factors. The major factors are:[1]

1. Raw materials.
2. Market.
3. Transportation.
4. Labor.
5. Plant requirements.
6. Power.

A wheel on plant location showing graphically the interrelation of all major and minor factors has been presented by Warner[2] in Fig. 67. After the relative importance of each of these factors has been diligently studied with due regard to present conditions and future developments, a conclusion will be reached which will confine the industry under consideration to a limited area, or perhaps to several such limited areas. The problem now resolves itself into choosing a plant or site in one of these areas. It is the solution of this problem which is particularly difficult for the manufacturer, owing to the fact that there are so many special conditions characteristic of the industry which have to be taken into consideration. A number of minor factors now must be diligently studied so that in the final analysis the most economical location will be selected.

The minor factors influencing selection of a plant site may be classified as follows:

7. Land.
8. Ordinances: nuisance, zoning.
9. Public improvements.
10. Utilities.
11. Flood protection.
12. Police facilities.
13. Fire protection.
14. Traffic congestion.
15. Room for expansion.
16. Tax rates.
17. Building costs.
18. Soil structure.
19. Topography.
20. Economic relation to other industries.
21. Waste disposal.
22. Climatic conditions.
23. Living conditions.

The nature of the enterprise determines the relative importance of the different factors. There must be a combination of all, and the ideal combination is rarely, if ever, attained. The successful corporation is continually correlating and uniting these factors; oftentimes conditions arise which warrant the subordination of one or more factors.

[1] HARTFORD, F. D., *Chem. Met. Eng.*, **38**, 72 (1931).

[2] WARNER, J. L., *Trans. Am. Inst. Chem. Engrs.*, **32**, 143 (1936).

The classical principle of plant location as stated by Holmes[1] was to determine that location which, in consideration of all factors affecting delivered-to-customers cost of the product to be manufactured, would afford the greatest advantage to be obtained by virtue of location. This principle states that the best location is that in which the sum of the cost of raw materials, all transportation charges and all manufacturing expenses for the product, delivered to the customer, will be at a minimum. In considering location from this standpoint, the problem may be studied from the angle of general area and then from the more specific standpoint of the definite region and actual site.

Three general classifications[2] of factors are encountered in the solution of any location problem. First are those factors relating directly to production, including labor, raw materials, power, fuel and water supply. The second class comprises those factors affecting distribution, including transportation facilities and rates, location of markets, and location of competitive industries. The third group affects both production and distribution, but also includes climate and legislative factors.

Economic Factors of Plant Location

Factors of Production

1. Raw materials or semifinished products: quality, reserve, proximity to plant; competitive sources.
2. Labor: supply and cost in kind, nationality, quantity, diversity, intelligence, wage scales, efficiency.
3. Water: sources, mineral analysis, bacterial content, turbidity, quantity, seasonal temperatures, costs.
4. Power: hydroelectric, public service, alternate sources.
5. Fuel: kinds, thermal efficiency, reserve, alternate sources.

Factors of Distribution

1. Transportation facilities: railroads, steamship lines, barge lines, terminals, wharves.
2. Freight rates: competitive points, differentials, favorable territory.
3. Markets: local area, favorable area, competitive area, national area.
4. Competitive, feeder, and consumer industries.

Production and Distribution Factors

1. Climate: seasonal range, precipitation, humidity, wind, etc.
2. Taxes and corporation fees.
3. Municipal restrictions: nuisance laws relating to fumes, waste disposal, etc.

[1] Holmes, W. G., "Plant Location," McGraw-Hill Book Company, Inc., New York, 1930.

[2] Perry, J. H., and C. W. Cuno, *Chem. Met. Eng.*, **41**, 439 (1934).

1. Raw Materials.—Probably the location of the raw materials of an industry contributes more toward the choice of a plant site than any other factor. This is especially noticeable in those industries in which the raw material is inexpensive and bulky and is made more compact and obtains a high bulk value during the process of manufacture. The steel mills are located near the iron mines or at some intermediate point between the iron and the coal mines. The flour mills in the Middle West are near the wheat fields, and the cotton mills in the heart of the cotton-growing section. The meat-packing industry in the United States is close to the great western fields upon which the herds are raised, and at the head of a transportation system feeding an extensive market.

The salt, gypsum, sodium sulphate, soda ash, carbonates, borax, natural nitrate and many other industries that take their raw materials from saline residues are all, by necessity, located directly at the source of supply. The location in West Virginia of a company for the manufacture of synthetic ammonia was for the purpose of being near the coal fields that supply the necessary raw materials.

Physical distance is not the only controlling factor in the source of raw materials, but purchase price and buying expense, reserve stock and reliability of supply are also determinants.

2. Market for Finished Product.—The question of market probably assumes greater importance for the intermediate and smaller industries, since such groups generally wish to deal directly with the market and dispense with the services of a middleman in disposing of the product. The concentration of industries in the larger cities is evidence of this fact.

The location of warehouses is largely a question of market. Large tonnages of steel are shipped by barge or lake boat to warehouses at the end of the water route, for final distribution of the material by rail. Grain is loaded direct from elevators at the head of the lakes and shipped to Buffalo where it is unloaded from boats to elevators for redistribution. Water shipments are economical where rail handling at the loading and delivery points can be kept down to a minimum, and where the water haul is long enough to accumulate a saving as compared to all-rail freight.

The large oil refineries are located along the seacoast or near large cities where a market exists for the finished products.

TABLE 115.—CHEMICAL RAW MATERIAL SOURCES—PRESENT AND POTENTIAL[1]

Metals[2]	
Arsenic	Mont., *Utah*, *Idaho*.
Antimony	Idaho, Calif., Nev., *Wash.*, *Ariz.*,* *Ark.*,* *Ore.**
Bauxite	Ark., Ala., *Ga.*, *Tenn.** *Miss.**
Bismuth	Calif., N. J., *Utah*, *Idaho*.
Chromium	Calif., Ore., *Mont.*, *Wash.*, *Wyo.*,* *Md.*,* *Penna.**
Copper	Ariz., Utah, Mont., Mich., *Nev.*, *N. M.*, *Colo.*, *Wash.*
Iron ore	Minn., Ala., Mich., Pa., *Wis.*, *Wyo.*, *N. J.*
Lead	Mo., Idaho, Utah, Okla., *Ariz.*, *Kans.*, *Colo.*
Manganese	Mont., Tenn., *Ga.*, *Ark.*, *Minn.*, *N. M.*, *Va.*,* *Wash.**
Mercury	Calif., Ore., Tex., *Nev.*, *Ark.*, *Ariz.*, *Idaho*,* *Wash.**
Molybdenum	Colo., Utah, Ariz., *N. M.*, *Wash.*,* *Wis.*, *Nev.**
Nickel	*Conn.*,* *Pa.*,* *Calif.**
Pyrites	Tenn., Va., N. Y., Calif., *Kans.*, *Ill.*, *Mo.*, *Ind.*,* *Colo.**
Silver	Idaho, Utah, Colo., *Ariz.*, *Calif.*, *Mont.*, *Nev.*
Titanium	Va., *Ark.*, *Calif.**
Tungsten	Nev., Calif., Colo., *Wash.*, *Idaho*, *Mont.*,* *Ariz.**
Vanadium	Colo., Ariz., *Utah*.
Zinc	Okla., N. J., Kans., Idaho, *Mont.*, *N. M.*, *Utah*, *N. Y.*
Nonmetals[2]	
Asbestos	Vt., Ariz., Md., *Mont.*, *N. C.*, *S. C.*, *Ga.*,* *Va.**
Asphalt	Ky., Ala., Tex., Okla., *Utah*, *N. M.*, *Calif.*, *Kans.**
Barite	Mo., Ga., Calif., Tenn., *Ariz.*, *Ala.*, *Colo.*, *Mont.*,* *Tex.**
Bentonite	Wyo., S. D., Tex., *Calif.*, *Ariz.*, *N. M.*, *Okla.*,* *Utah.**
Borates	Calif., *Nev.*
Bromine	N. C., Mich., *Calif.*, *W. Va.*, *Tex.**
Calcium-magnesium chloride.	Mich., W. Va., *Ohio*.
Ball clay	Ky., Tenn., Mo., *N. J.*, *Calif.*, *Ill.*
Fire clay	Pa., Ohio, Mo., Ky., *Ill.*, *Calif.*, *N. J.*, *Colo.*
Fuller's earth	Ga., Fla., Tex., *Calif.*, *Colo.*, *Ill.*, *Nev.*, *Tenn.*
China clay	Ga., S. C., Pa., *N. C.*, *Calif.*, *Mo.*, *Va.*, *Ala.*
Miscellaneous clays.	Calif., Colo., Pa., Ohio, *Ia.*, *Wash.*, *Nebr.* *Ind.*,
Anthracite coal.	Pa.

[1] States are listed in order of importance of value of goods produced. States in roman type are principal producers, those in italics are producers of less importance.

[2] From U.S. Bureau of Mines, 1939.

* Potential producers.

TABLE 115.—CHEMICAL RAW MATERIAL SOURCES—PRESENT AND POTENTIAL.[1]—(*Continued*)

Bituminous coal.	W. Va., Pa., Ill., Ky., *Ohio, Ind., Ala., Va., Wyo.*
Lignite	N. D., Tex., *Mont., S. D.*
Peat	N. Y., N. J., Mich., *Calif., Conn., Fla., Ia.*
Feldspar	S. D., Tenn., Colo., N. C., *N. H., Ariz., Va., N. J.*
Fluorspar	Ill., Ky., N. M., *Nev., Colo., N. H.*
Graphite	Nev., *N. Y., Ga.*
Gypsum	N. Y., Mich., Ia., Tex., *Calif., Nev., Okla., Utah.*
Helium	Tex., *Kans.,* Colo.**
Iodine	Calif., *La.**
Limestone and dolomite.	Mich., Ohio, Pa., N. Y., *Ill., Ohio, Ky., Mo., Tenn.*
Lithium	S. D., *Calif., N. C.**
Magnesite	Wash., Calif., *Vt.,* Tex.,* Ohio.**
Mg salts	Mich., Nev., Calif., *Wash.*
Natural gas	Tex., Calif., La., Okla., *Kans., N. M., W. Va., Pa.*
Petroleum (crude).	Tex., Calif., Okla., La., *Ill., Kans., N. M., Pa., Wyo.*
Phosphate rock.	Fla., Tenn., *Mont., Idaho, Va.**
Potash salts	N. M., Calif., *Utah.*
Salt	Mich., N. Y., La., Ohio, *Kans., Calif., W. Va., Tex.*
Sand (glass)	N. J., N. Y., Mich., *Ill., Ohio, Pa., Va.*
Sodium carbonate.	Calif., *Ore.,* Wyo.**
Sulfur	Tex., La., *Calif.,* Utah.**
Talc	N. Y., Vt., N. C., *Calif., Ga., Pa., Va.*
Vermiculite	Wyo., Mont., *N. C., Colo.**
Agricultural Products[2]	
Corn	Ia., Ill., Ind., Minn., *Ohio, Nebr., Mo., Wis.*
Cottonseed	Tex., Miss., Ark., Ala., *Ga., La., S. C., Okla.*
Flaxseed	Minn., N. D., Calif., *S. D., Kans., Mont.*
Milk (by-products).	Wis., Minn., N. Y., Ia., *Ill., Pa., Tex., Mich.*
Oat hulls	Ia., Minn., Ill., Wis., *Nebr., S. D., Mo., Mich.*
Pulpwood	Wash., Maine, Wis., *La., N. Y., Va.*
Soybean	Ill., Ind., Ia., *Ohio, N. C., Mo.*
Sugar beets	Calif., Colo., Idaho, *Nebr., Mich., Mont.*
Sugar cane	La., Fla., Miss., *Ga., Tex., Ark.*
Tung oil	Miss., Fla., La., *Ga., Tex., Ala.*
Yellow pine	Ga., Fla., Miss., *S. C., N. C., La.*

[1] States are listed in order of importance of value of goods produced. States in roman type are principal producers, those in italics are producers of less importance.

[2] From U.S. Department of Agriculture, 1938.

* Potential producers.

Crude oil is easily pumped by pipe lines or shipped from the oil wells in the interior; cheap rates are thus secured for a crude, low-priced commodity, consumed in large quantities, while the finished products are made in the center of the market in order to lower the distribution cost.

3. Transportation.—The existence of transportation facilities has given rise to many of the greatest trade centers of the world. The character of a business will, however, determine the type of transportation used. The relation of railway to market is so close that no pains should be spared in making a careful investigation of freight rates before definitely deciding upon a plant location. A location should be chosen, if possible, which has several competing railroads and waterways in order that the competition will help to maintain low rates and give better service. The widespread use of motor trucking facilities, following the comparatively recent development of good interconnecting roadways, has supplemented and in some cases even supplanted the railroads. The formation of organizations which will pick up and deliver odd lots of freight has been a great help to isolated factories in the smaller towns.

As a general rule it may be stated that the ideal location would be one in which the heavy raw materials and fuel are brought in by canal or other waterways, and the finished material taken away by one or more lines of railway. Industries that are national in scope find an advantage in locations where the transportation of a low-priced, bulky raw material is feasible, rather than where a high-priced material of small bulk must be transported. This is, however, only another example of the result of a profitable balance between raw material, transportation and market.

The location of the large sugar refineries along the seacoast is dictated by the fact that the raw, unrefined sugar is received by boats from the sugar-producing countries of the south. It would seem that economical factors would force the refining to be done at the place where the sugar is produced. However, the refineries are not in the countries that produce the raw sugar, but exist owing to peculiarities of process and in order to circumvent import duties that are placed on the refined product. The present methods of sugar refining dictate that the plant should be located close to an unlimited supply of pure water and

cheap fuel. Ultimately, refinements in process may permit the granulated sugar to be made directly on the plantation, thus giving the raw-sugar producer an opportunity to operate his plant the year round instead of only during the harvesting season.

The freight rate probably plays a greater part in the success of chemical plants than in any other industry. The raw material is obtained from certain sections of the country, in some cases very much isolated, and the price is regulated largely by the cost of transportation to consumers.

The rapid rise in freight rates during the past 10 years has been a strong contributing factor in causing many of the larger and older plants, located in cities, to seek new locations. Oftentimes, a location is selected outside the city limits in order to have a railroad siding available, and thus eliminate trucking costs to freight yards from the excessive cost of transportation.

4. Labor Sources.—Before locating an industry in any particular locality, a careful study of the class and supply of available labor must be made. It is also necessary to ckeck up on labor rates and restrictions in regard to the number of hours per week for both male and female labor, etc. Factors to be considered on labor are supply, kind, nationality, diversity, intelligence. wage scales, efficiency and costs.

The success of many an organization is dependent upon the means by which its laborers get to and from their work. Laborers sometimes live at great distances from the work. A cheap site may have been chosen but no attention given to the housing facilities. The workmen arrive tired at the start of a day's work and must travel a great distance at its close. Thus what may have appeared to be a cheap location develops into a very expensive one on account of the extraordinary labor turnover. Such examples are familiar.

Industrial housing, safety-first movements, welfare institutions, better sanitation, lunchrooms, etc., have all contributed to the solution of labor problems; the radio and automobile, also, have helped toward building up and maintaining a supply of satisfied and contented laborers.

Labor surveys reveal the discrepancy in wage rates throughout the country and the industries. The equalizing of rates in each industry was attempted in the codification of industries in the

United States under the National Recovery Act of 1935. Data on rates in each industry can be obtained from labor boards in each region.

5. Water.—Manufacture of many chemical products—heavy acids, paper, leather and beet sugar, for example—requires quantities of water for cooling or washing that only a river or a lake can supply. Filtered water for such purposes usually is not necessary. The primary requisite is dependability—the necessary quantity of water at any and all times. If not too large quantities of water are required, a site should be chosen where a deep well or perhaps an artesian well may be drilled at a reasonable cost, if one of these is not already on the property. In investigating this problem considerable help may be obtained by consulting the state geological survey, which can furnish valuable information regarding subterranean waters in every district. An inspection of the wells in the vicinity will give a good indication of the depth necessary to drill on the site under consideration. The quantity of water taken from the neighboring wells may affect the amount of water available. The quality of the water in neighboring wells will give a good indication of the water that can be expected. This latter consideration is particularly important where process water is required.

Quality of water, such as mineral constituents, and temperature of the water must be considered. Wood pulp and paper, and the gelatin industry, together with all plants operating boilers, require a relatively pure water. Where water is to be used for cooling and condensing purposes, the temperature is an important item for consideration.

Dissolved impurities in raw water for cooling and washing usually are of little consequence, but this is not true of materials carried mechanically. At certain seasons, river waters may be heavily charged with silt or sand, which wear pumps excessively or clog piping, nozzles and tanks; or they may carry large quantities of floating trash or ice, almost certain to cause trouble at the intake. Another aspect of water supply from rivers is the possibility of floods on the one hand, and the chance of extremely low water on the other.

A city water supply is an easy, if not an economical, solution to a water-supply problem. The quality of the water is easy to ascertain; it is extremely important to ascertain the size and

condition of the supply mains, the normal and reserve supply, and the pressure conditions.

6. Power.—The question of power supply is taking an increasingly important place in the selection of factory locations. The manufacturer has the choice of a situation at the source of raw materials, at the coal mines, or at the water front. In pulp and paper, Portland cement and glass and clay products, the source of fuel and power is of equal importance to the previously mentioned factors. In the electrochemical industry, this is dominant, but in others the source of fuel and power is not so important a location factor. Niagara Falls is the outstanding example of a location where power is a prime consideration. This region has become the center of the electrochemical industry of the United States, where such important materials as aluminum, caustic soda and chlorine are manufactured. Some of the largest generating and distributing companies in the country, however, have recently been developed in the south and offer power rates which compare favorably with the northern locations. Kanawha River Valley, W. Va., and the region under Tennessee Valley Authority are growing rapidly as industrial centers owing to proximity to the coal mines in the one case, and cheap hydroelectric power in the other.

7. Land.—In choosing a site the characteristics of the ground should be carefully investigated to ascertain whether it is virgin or filled-in land. Borings should be made to determine whether piling is required and, if so, to what extent. Piling adds considerably to the foundation cost of a building and such land, even though purchased cheaply, may prove to be very expensive.

8. Ordinances.—Chemical plants are not usually looked upon as desirable neighbors. They may be regarded as a source of danger from possible explosion, or, because of fumes, as a detriment to the health of the community and to its vegetation. The result of propaganda against the chemical industry has been that many communities have passed ordinances against chemical manufacturing or certain classes of chemical manufacturing. It is advisable to ascertain whether the attitude of the community is particularly unfriendly to chemical manufacturing; if this is the case, it is good policy to go elsewhere even though no restricting ordinances are in effect at the time. Such information can usually be obtained from the local chamber of commerce

or board of trade, or by making inquiries at other plants in the locality.

Most large cities and many of the smaller towns are zoned, *i.e.*, divided into residential, business and unrestricted districts. A distinction is often made between so-called light manufacturing and heavy manufacturing. Chemical plants generally must locate in heavy or unrestricted zones. Zoning regulations must, therefore, be carefully investigated. Where such regulations are in force, a map is usually published outlining the various zones. As the boundaries of these zones are subject to small changes at frequent intervals, care must be taken to ascertain that the zoning map has been corrected to date. An unrestricted zone may even be slowly changing in character on account of the encroachment of residences, parks of other civic developments.

If the industry for which a location is to be chosen is in any way hazardous, or is likely to be a nuisance owing to the possible escape of fumes or objectionable odors, a site should be selected which is at a considerable distance from houses and public institutions. This is a precaution that is frequently overlooked, which if not heeded may cause endless trouble and expense.

If there are other plants in the immediate neighborhood of a site under consideration, it is advisable to find out what products these plants are manufacturing and by what methods. For example an adjoining plant manufacturing a highly flammable product would affect the insurance rate if its buildings were sufficiently close. The neighboring plant may also give out dust or fumes which may affect the product to be manufactured.

9. Public Improvements.—The introduction of public improvements, such as park extensions and boulevard extensions, and the conversion of swamps and unsightly public dumps, etc., into industrial areas, should be attended by a proper attitude of mind on the part of public officials, so that unnecessary and destructive limitations will not be placed upon such areas, nor the tax burden become prohibitive. Such improvements, on the other hand, add considerably to the upbuilding of the morale and welfare of the employees.

10. Utilities.—The availability of public-utility gas and electricity is almost always an asset to any plant, as these services can usually be purchased at a cost lower than that of operating private units in the plant. Even when gas or electricity are

made in the plant, an outside source is of considerable value for emergency purposes.

Fire apparatus provided in the average American city is for the most part adequate. So far as the location of the chemical plant is concerned, the important desideratum is that the fire apparatus be but a few minutes distant. If deep snow, congested traffic, bridge washouts or stalled freight trains can prevent firemen from reaching a factory quickly, then a site subject to such conditions should be avoided. Often it is necessary to establish and maintain a company fire station and man it with volunteers or with full-time firemen.

In cities without a definite industrial district, the plant may become engulfed in a residential or a business area. A relatively permanent obstruction such as a railroad yard, a swamp or a river will divert future community growth.

11. Economic Relation to Other Industries.—As a rule, a chemical plant will have a better chance of success if located near others of like nature. A group of plants can obtain favorable rail rates, better service from utilities and plentiful supply of labor. Better banking and technical service are thus available, since familiarity with the needs of the industry results in segregation of knowledge and the establishment of sound credit relationships. Utilization of wastes from related plants or similarity of disposal offers unusual opportunities for economies.

12. Waste Disposal.—Disposal of waste liquors and waste products is frequently a problem for the chemical plant and, therefore, must be given serious consideration in choosing a site. If there is a sewer in the street adjoining the property, the quantity of liquor to be disposed of should be estimated and the size of street sewer checked to determine whether it can take care of the liquor. If the waste liquor is acid or alkaline, contains solids or has other objectionable features, it is advisable to learn from the local authorities whether the disposal of such liquor in the sewerage is permissible.

Chemical plants often dispose of their waste by locating on a stream, river or at tidewater. Disposal by tidewater is often satisfactory if there are no bathing beaches near by. Disposal of waste into a stream or river is not so satisfactory, for there is a growing tendency in various parts of the country to legislate against such pollution by industrial wastes.

Another method of waste disposal is by seepage through the ground. If such a method is to be used, soil tests should be made to determine whether the soil is porous enough to permit the disposal of considerable quantities of liquor without accumulation. It is also advisable to check the topography of the area to determine where the liquor will seep in order to avoid trouble from neighboring plants or the local authorities. Towns lower down the valley may draw their water supply from the drainage shed upon which the plant is situated.

TABLE 116.—TYPICAL FACTORS DETERMINING PLANT LOCATION[1]
(As employed in locating a mill for the International Nickel Co.)

Factor	Relative weight, units	Other considerations
Labor	250	Skilled or common; supply; rates; strikes
Fuels (for metallurgical power generation)	330	Cost and quality; oil; producer gas; natural gas; coal; coke
Power	100	Public service electric supply; costs; service
Living conditions	100	Housing; cost of living; sanitation and health
Climate	50	Minimum, maximum and average temperatures; average snowfall; average rainfall
Supplies	60	Sources and costs; matte; refractories; rolls, castings and mill spares; sheet; bars; charcoal; electrodes; lubricating oils; general stores
Transportation (railroads and water)	50	Distribution of products; domestic and export shipping; Monel and nickel shot; pig, sheet, wire, rod; forgings
Water supply	10	Service costs; quality
Taxes and laws	20	State; local ordinances
Selection of site	10	Railroad connections; character of ground for building and equipment foundations; drainage and flood conditions; accessibility for labor; grading and facilities for slag disposal; provision for expansion of works
Construction costs	20	Labor; materials; supplies

[1] McBRIDE, R. S., *Chem. Met. Eng.*, **29**, 746 (1923).

13. Climatic Conditions.—Chemical plants as a general rule are rather difficult to insulate, or to provide with artificial heat or conditioned air, except in the individual process units where air conditioning is essential. Usually the workmen are forced to "grin and bear it" to the detriment of production costs and yields. Excessive cold, deep snows, torrid heat and excessive humidity reduce the productivity on the part of the workmen. Other factors being approximately equal, the plant locator should weigh carefully the climatic values of various sites, so that few hindrances to economical operation may obtain.

Factors in Selection of Area.—The broad characteristics of the principal regional state groupings, *viz.*, New England, Middle Atlantic, South Atlantic, East South Central, East North Central, West North Central, Mountain and Pacific areas are given by the editorial staff in the May, 1941, issue of *Chemical & Metallurgical Engineering.*

One of the most extensive bibliographies of plant location information assembled is the compilation of source material by Perry and Cuno, which was published on pages 439–442 of the August, 1934, issue of *Chemical & Metallurgical Engineering.* This bibliography has been brought up to date on pages 121–122 of the May, 1941, issue of the same magazine.

QUANTITATIVE ANALYSIS OF LOCATION FACTORS

McBride has shown by a tabulation reproduced in Table 116 that each of the above factors may be given some relative rating, the value of each depending upon its importance or its dominance in the case at point. Setting up such a table for a particular industry, and rating selected localities according to such ratings, is a scientific method of selecting a plant location.

If it is at all possible to do so the choosing of a site which seems to hold promise should be based upon comparisons with similar figures for other locations. By a process of trial and error, and the introduction of some judgment, a final answer may thus be reached.

A compilation of data on certain factors involved in choice of plant location, essential to a quantitative analysis of location factors as compiled by the editorial staff of *Chemical & Metallurgical Engineering*, is given in Table 117.

TABLE 117.—DATA ON CERTAIN FACTORS INVOLVED IN CHOICE OF PLANT LOCATION

State and geographical area	Population[1]			Electric power		Transportation				Industrialization				Water supply[9]		
				Installed public utility generator capacity[3]		Railroads		Motor trucks		As percentage of United States total				Average p.p.m. expressed as $CaCO_3$		
	Total, 1940	Percentage change, 1930–1940	Percentage urban, 1940[2]	Water power, 1,000 kw.	Steam power, 1,000 kw.	Mileage operated[4]	Miles per square mile state[5]	Total registered[6]	Trucks per square mile state[5]	Wage earners[7]	Total wages[7]	Value added by manufacturer[7]	Process industries[8]	Surface water	Ground water	Average for all water
United States	131,669,275	7.2%	56.5*%	11,556	28,526	247,073	0.084	4,320,829	1.47	100.00	100.00	100.00	100.00	85	191	102
New England	8,437,290	3.3	76.1	877	2,170	6,964	0.112	270,499	4.37	12.09	11.26	9.84	4.91			
Maine	847,226	6.2	40.5*	216	70	1,985	0.066	43,000	1.43	0.96	0.75	0.62	1.12	15	...	15
New Hampshire	491,524	5.6	57.6	236	71	1,080	0.120	25,400	2.82	0.71	0.58	0.43	0.19	11	35	19
Vermont	359,231	−0.1	34.3*	167	11	977	0.107	9,576	1.05	0.28	0.23	0.21	0.10	63	...	63
Massachusetts	4,316,721	1.6	89.4	164	1,189	1,857	0.232	106,624	13.25	5.83	5.50	4.82	2.76	19	47	21
Rhode Island	713,346	3.8	91.6	3	235	180	0.172	20,526	19.25	1.35	1.16	0.96	0.20	28	24	27
Connecticut	1,709,242	6.4	67.8	90	584	885	0.183	66,273	13.73	2.96	3.04	2.80	0.54	24	...	24
Middle Atlantic	27,539,487	4.9	76.8	1,568	8,076	22,171	0.221	717,699	7.18	28.52	29.58	29.83	19.46			
New York	13,479,142	7.1	82.8	1,166	4,315	8,195	0.172	315,818	6.70	12.14	12.80	13.56	8.93	47	117	55
New Jersey	4,160,165	2.9	81.6	7	1,119	2,431	0.324	132,819	17.60	5.50	5.74	6.18	8.81	53	128	71
Pennsylvania	9,900,180	2.8	66.5	395	2,641	11,545	0.256	269,062	6.12	10.88	11.04	10.09	10.72	78	208	83
East North Central	26,626,342	5.3	65.5	709	8,508	43,794	0.176	775,497	3.13	27.85	32.46	31.47	28.27			
Ohio	6,907,612	3.9	66.8	13	2,409	8,977	0.221	184,223	4.49	7.59	7.94	8.60	10.31	125	333	160
Indiana	3,427,796	5.8	55.1	35	1,231	7,124	0.179	126,000	3.19	3.52	3.80	3.93	5.03	199	361	243
Illinois	7,897,241	3.5	73.6	52	2,547	13,231	0.234	232,888	4.16	7.56	8.25	8.91	6.83	127	345	148
Michigan	5,256,106	8.5	65.7	344	1,616	7,500	0.131	90,796	1.60	6.63	8.70	7.25	3.97	114	303	137
Wisconsin	3,137,587	6.8	53.5*	267	704	6,962	0.128	141,590	2.60	2.55	2.77	2.78	2.13	129	247	163
West North Central	13,516,990	1.7	44.3*	539	2,412	50,782	0.100	585,392	1.15	4.85	4.72	5.52	3.67			
Minnesota	2,792,300	8.9	49.8*	157	497	9,013	0.114	118,227	1.50	1.01	1.07	1.26	0.86	154	290	173
Iowa	2,538,268	2.7	42.7*	127	507	9,483	0.171	93,139	1.68	0.83	0.81	0.99	0.34	160	347	277
Missouri	3,784,664	4.3	51.8*	158	607	7,766	0.113	142,200	2.07	2.26	2.10	2.38	1.16	133	276	134
North Dakota	641,935	−5.7	20.6*	0	82	5,270	0.075	34,544	0.49	0.04	0.03	0.05	.....	153	262	185
South Dakota	642,961	−7.2	24.6*	4	53	4,139	0.054	30,282	0.39	0.07	0.07	0.08	.....	239	478	395
Nebraska	1,315,834	−4.5	39.1*	86	224	6,193	0.081	67,000	0.87	0.24	0.23	0.28	0.04	251	150	213
Kansas	1,801,028	−4.3	41.9*	7	442	8,918	0.109	100,000	1.22	0.40	0.41	0.48	1.27	187	401	274
South Atlantic	17,823,151	12.9	38.8*	2,137	2,863	25,421	0.093	489,270	1.78	12.51	9.08	9.06	7.38			
Delaware	266,505	11.8	52.3*	0	33	298	0.152	13,500	6.92	0.26	0.24	0.22	0.20	48	85	53
Maryland	1,821,244	11.6	59.3	271	405	1,441	0.146	58,027	5.86	1.80	1.72	1.72	1.09	53	21	53

Dist. of Columbia	663,091	36.2	100.0	2	255	52	0.870	15,433	257.20	0.10	0.13	0.18	0.01	90	...	90
Virginia	2,677,773	10.6	35.3*	184	421	4,435	0.110	68,723	1.71	1.70	1.27	1.54	1.99	43	164	56
West Virginia	1,901,974	10.0	28.1	101	627	4,094	0.165	46,537	1.88	0.95	0.97	0.87	1.93	71	172	93
North Carolina	3,571,623	12.7	27.3*	709	480	4,826	0.099	81,068	1.67	3.42	2.19	2.21	0.58	25	95	28
South Carolina	1,899,804	9.3	24.5*	516	138	3,533	0.114	44,142	1.44	1.61	0.95	0.69	0.35	22	24	22
Georgia	3,123,723	7.4	34.4*	340	141	6,622	0.111	85,520	1.44	2.00	1.19	1.15	0.90	18	116	41
Florida	1,897,414	29.2	55.1*	14	364	5,353	0.092	76,320	1.30	0.67	0.42	0.48	0.33	81	173	148
East South Central	10,778,225	9.0	29.4*	1,367	756	17,116	0.095	243,615	1.35	4.54	3.20	3.36	4.28			
Kentucky	2,845,627	8.8	29.8	111	257	3,872	0.096	69,629	1.72	0.80	0.68	0.76	0.96	105	...	105
Tennessee	2,915,841	11.4	35.2*	512	195	3,862	0.093	64,039	1.54	1.67	1.21	1.30	1.78	82	44	65
Alabama	2,832,961	7.1	30.2*	743	255	5,302	0.103	54,947	1.07	1.48	1.01	1.00	0.85	53	50	52
Mississippi	2,183,796	8.7	19.8*	0	49	4,080	0.087	55,000	1.19	0.59	0.30	0.30	0.69	52	27	36
West South Central	13,064,525	7.3	39.8*	153	1,752	33,089	0.083	576,267	1.44	3.33	2.63	3.37	13.28			
Arkansas	1,949,387	5.1	22.2*	67	74	4,714	0.089	60,535	1.14	0.46	0.27	0.27	0.41	133	44	106
Louisiana	2,363,880	12.5	41.5*	0	375	4,847	0.107	84,475	1.86	0.90	0.61	0.84	2.30	65	43	62
Oklahoma	2,336,434	−2.5	37.6*	2	316	6,389	0.165	95,790	2.46	0.36	0.34	0.42	1.73	139	246	156
Texas	6,414,824	10.1	45.4*	84	987	17,139	0.065	335,467	1.28	1.61	1.41	1.84	8.84	127	143	135
Mountain	4,150,003	12.1	42.7*	1,584	505	24,786	0.029	204,936	0.24	0.88	0.89	1.12	1.32			
Montana	559,456	4.1	37.8*	321	12	5,235	0.036	44,480	0.31	0.12	0.13	0.16	0.13	94	234	98
Idaho	524,873	17.9	33.7*	257	0.8	3,231	0.038	30,000	0.35	0.14	0.14	0.13	0.02	74	99	85
Wyoming	250,742	11.2	37.3*	49	34	2,009	0.023	18,090	0.19	0.04	0.05	0.06	0.33	106	224	154
Colorado	1,123,296	8.4	52.6*	66	211	5,120	0.049	30,636	0.30	0.30	0.31	0.37	0.71	122	...	122
New Mexico	531,818	25.6	33.2*	0.9	92	2,907	0.024	28,488	0.23	0.04	0.03	0.04	0.06	62	259	205
Arizona	499,261	14.6	34.8*	293	94	2,193	0.020	24,000	0.21	0.08	0.08	0.13	0.05	......	207	207
Utah	550,310	8.4	55.5*	92	60	2,220	0.027	21,204	0.26	0.15	0.13	0.18	0.02	170	174	171
Nevada	110,247	21.1	39.3*	504	2	1,871	0.017	8,038	0.073	0.01	0.02	0.05	......	83*	187	143
Pacific	9,733,262	18.8	65.3	2,621	1,485	17,719	0.056	456,754	1.44	5.45	6.17	6.48	9.08			
Washington	1,736,191	11.1	53.1	800	219	5,938	0.089	84,150	1.26	1.15	1.30	1.16	1.17	22	112	41
Oregon	1,089,684	14.2	48.8	279	179	3,646	0.039	62,749	0.66	0.81	0.85	0.70	0.33	10	29	13
California	6,907,387	21.7	71.0	1,543	1,088	8,135	0.052	309,855	1.98	3.49	4.02	4.62	7.58	128	150	133

Chem. Met. Eng., **48**, 5—86 (1941).

1 Bureau of Census, U.S. Dept. of Commerce, Series P-3, No. 7, Jan. 18, 1941.

2 Largely in towns, villages, etc., having 2,500 population or more.

3 Federal Power Commission preliminary as of Oct. 1, 1940. Includes central stations, municipal, railway and other for plants operated both by one type of prime mover and by combination of two or more types. Does not include that generated by internal combustion engines.

4 Association of American Railroads. Includes miles of single track operated (miles of right of way) by Class I, II, and III, of steam railways, exclusive of switching and terminal companies.

5 Calculated on basis of land area of each state.

6 From U.S. Public Roads Administration, as of Dec. 31, 1939. Figures for New Hampshire, Ohio, Illinois, Michigan, Iowa, Delaware, Montana, and California include a relatively small number of buses.

7 Census of Manufactures, 1939. 8 Census of Manufactures, 1937. Process industry percentages calculated on basis of value of product.

9 U.S. Geological Survey, Water Supply Paper No. 658.

* Denotes an increase in percentage of urban population, 1930–1940.

Suggested Collateral Reading

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APPENDIX A

GENERAL TABLES

TABLE I.—METRIC EQUIVALENTS

Weights (English to Metric)

1 grain	64.79892	mg.
1 ounce, Troy	31.10348	g.
1 ounce, avoirdupois	28.34953	g.
1 pound, avoirdupois	0.45359	kg.
1 net ton, 2,000 pounds	0.90718	tonne
1 gross ton, 2,240 pounds	1.01605	tonnes

Linear Measure

1-64th of an inch	0.39688	mm.
1 inch	2.54001	cm.
1 foot	0.304801	m.
1 yard	0.914402	m.
1 statute mile	1.60935	km.
1 nautical mile	1.85325	km.
1 Gunter's chain	20.1168	m.
1 fathom	1.829	m.

Square Measure

1 square inch	6.45163	sq. cm.
1 square foot	0.09290	sq. m.
1 square yard	0.83613	sq. m.
1 acre	0.40470	hectare
1 square mile	2.59000	sq. km.

Cubic Measure

1 cubic inch	16.38716	c.c.
1 cubic inch	0.01639	cu. dm.
1 cubic foot	0.02832	cu. m.
1 cubic yard	0.76456	cu. m.

Capacity Measure

1 liquid quart	0.94636	l.
1 U. S. gallon, 231 cubic inches	3.78543	l.
1 U. S. gallon, 231 cubic inches	0.00379	cu. m.
1 bushel	0.35239	hectoliter
1 fluid drachm	3.69671	c.c.
1 fluid ounce	29.57370	c.c.

TABLE I.—METRIC EQUIVALENTS.—(*Continued*)

Miscellaneous

1 pound per lineal foot	1.48816	kg. per lin. m.
1 pound per square inch	0.07031	kg. per sq. m.
1 pound per square foot	4.88241	kg. per sq. m.
1 pound per cubic foot	16.01837	kg. per cu. m.
1 foot-pound	0.13826	kg.-m.
1 U. S. horsepower	1.01387	metric hp.

Weights (Metric to English)

1 milligram	0.01543	grain
1 gram	0.03215	oz., Troy
1 gram	0.03527	oz., avoirdupois
1 kilogram	2.20462	lb., avoirdupois
1 tonne	1.10231	net tons, 2,000 lb.
1 tonne	0.98421	gross ton, 2,240 lb.

Linear Measure

1 millimeter	2.51968	64ths in.
1 centimeter	0.39370	in.
1 meter	3.280833	ft.
1 meter	1 093611	yards
1 kilometer	0.62137	statute mile
1 kilometer	0.53959	nautical mile

Square Measure

1 square centimeter	0.15500	sq. in.
1 square meter	10.76387	sq. ft.
1 square meter	1.19599	sq. yards
1 hectare	2.47104	acres
1 square kilometer	0.38610	sq. mile

Cubic Measure

1 cubic centimeter	0.06102	cu. in.
1 cubic decimeter	61.02338	cu. in.
1 cubic meter	35.31445	cu. ft.
1 cubic meter	1.30794	cu. yards

Capacity Measure

1 liter	1.05668	fl. qt.
1 liter	0.26417	gal., 231 cu. in.
1 cubic meter	264.17047	gal., 231 cu. in.
1 hectoliter	2.83774	bu.
1 cubic centimeter	0.27051	fl. drachm
1 cubic centimeter	0.03381	fl. oz.

Miscellaneous

1 kilogram per lineal meter	0.67197	lb. per lin. ft.
1 kilogram per square centimeter	14.22340	lb. per sq. in.
1 kilogram per square meter	0.20482	lb. per sq. ft.
1 kilogram per cubic meter	0.06243	lb. per cu. ft.
1 kilogram-meter	7.23300	ft.-lb.
1 metric horsepower	0.98632	U. S. hp.

TABLE II.—SOME MISCELLANEOUS WEIGHTS AND MEASURES

Long Measure	
Fathom (nautical)	6 ft.
Light year	5.9×10^{12} miles
Link (surveyors)	0.66 ft.
Chain (engineers)	100.0 ft.
Chain (surveyors)	66.0 ft.
Furlong (British)	220 yd
Hand	4. in.
Point (printers)	$\frac{1}{72}$ in.
Pole (British)	5.5 yd.
Rod (surveyors)	25 links
Span	10.94 in.
Toise (French)	6 Paris ft.
Square Measure	
Acre	4,840 sq. yd.
Perch (British)	30.25 sq. yd.
Weight	
Carat	200 mg.
Hundredweight (British)	112 lb.
Hundredweight (U. S.)	100 lb.
Ounce (avoir)	437.5 g.
Ounce (fine)	480.0 g.
Stone (British)	14 lb.
Ton (long)	2240 lb.
Cubic Measure	
Barrel (wine)	42 gal.
Barrel	7056 cu. in.
Bushel (U. S.)	1.244 cu. ft.
Bushel (British Imp.)	1.284 cu. ft.
Gallon (U. S.)	231 cu. in.
Gallon (Imperial)	277.3 cu. in.
Dram	3.697 ml.
Minim (fl.)	$\frac{1}{480}$ ft.-oz.
Lumber Measure	
Board foot	1 ft. $\times$ 1 ft. $\times$ 1 in.
Cord	128 cu. ft.
Power and Speed	
Cheval (French)	0.986 hp.
Horsepower	33,000 ft. lb. per min. 746 watts.
Knot (nautical)	6080.22 ft. per hr.
Miner's inch	1.2 cu. ft. per min.

TABLE III.—INTERCONVERSION TABLE FOR UNITS OF VOLUME AND WEIGHT[1]

To convert from	Multiply by														
	To cu. in.	To cu. ft.	To cu. yd.	To fl. oz.	To pint	To quart	To gallon	To grain	To oz., Troy	To oz., av.	To lb., Troy	To lb., av.	To cc. or g.	To liter or kg.	To cu. m.
Cu. in.	1.00000	$0.0_{3}5787$	$0.0_{4}2143$	0.554112	0.034632	0.017316	0.004329	252.891	0.526857	0.578037	0.043905	0.036127	16.3871	0.016387	$0.0_{4}1639$
Cu. ft.	1728.00	1.00000	0.037037	957.505	59.8442	29.9221	7.48052	436996	910.408	998.848	75.8674	62.4280	28316.9	28.3169	0.028317
Cu. yd.	46656.0	27.0000	1.00000	25852.6	1615.79	807.896	201.974	117990_{3}	24581.0	26968.9	2048.42	1685.56	764556	764.556	0.764556
Fl. oz.	1.80469	0.001044	$0.0_{4}3868$	1.00000	0.062500	0.031250	0.007813	456.390	0.950813	1.04318	0.079234	0.065199	29.5736	0.029573	$0.0_{4}2957$
Pint	28.8750	0.016710	$0.0_{3}6189$	16.0000	1.00000	0.50000	0.125000	7302.23	15.2130	16.6908	1.26775	1.04318	473.177	0.473177	$0.0_{4}4732$
Quart	57.7500	0.033420	0.001238	32.0000	2.00000	1.00000	0.250000	1460.45	30.4260	33.3816	2.53550	2.08635	946.354	0.946354	$0.0_{3}9463$
U. S. gal.	231.000	0.133681	0.004951	128.000	8.00000	4.00000	1.00000	5841.79	121.704	133.527	10.1420	8.34541	3785.42	3.78542	0.003785
Grain	0.003954	$0.0_{5}2288$	$0.0_{7}8475$	0.002191	$0.0_{3}1369$	$0.0_{4}6850$	$0.0_{4}1712$	1.00000	0.002083	0.002286	$0.0_{3}1736$	$0.0_{3}1428$	0.064799	$0.0_{4}6479$	$0.0_{7}6479$
Oz., Troy	1.89805	0.001098	$0.0_{4}4068$	1.05173	0.065733	0.032867	0.008217	480.000	1.00000	1.09714	0.083333	0.068571	31.1035	0.031104	$0.0_{4}3110$
Oz., av.	1.72999	0.001001	$0.0_{4}3708$	0.958608	0.059913	0.029957	0.007489	437.500	0.911457	1.00000	0.075955	0.062500	28.3495	0.028350	$0.0_{4}2835$
Lb., Troy	22.7766	0.013181	$0.0_{3}4882$	12.6208	0.788800	0.394400	0.098600	5760.00	12.0000	13.1657	1.00000	0.822857	373.242	0.373242	$0.0_{3}3732$
Lb., av.	27.6799	0.016018	$0.0_{3}5933$	15.3378	0.958611	0.479306	0.119826	7000.00	14.5833	16.0000	1.21528	1.00000	453.593	0.453593	$0.0_{3}4536$
Cc. or gram	0.061024	$0.0_{4}3531$	$0.0_{5}1308$	0.033814	0.002113	0.001057	$0.0_{3}2642$	15.4323	0.032151	0.035274	0.002679	0.002205	1.00000	0.001000	0.000001
Liter or kg.	61.0237	0.035315	0.001308	33.8140	2.11337	1.05669	0.264172	15432.3	32.1507	35.2739	2.67923	2.20462	1000.00	1.00000	0.001000
Cu. m.	61023.7	35.3146	1.30795	33814.0	2113.37	1056.69	264.172	154320_{3}	32150.7	35273.9	2679.23	2204.62	1000000	1000.00	1.00000

Note.—The small subnumeral following a zero indicates that the zero is to be taken that number of times; thus, $0.0_{3}1428$ is equivalent to 0.0001428.

Values used in constructing table:

1 in. = 2.540001 cm.
1 cu. in. = 16.387083 c.c. = 16.387083 g. H_2O at 4°C. = 39°F.
1 lb. av. = 453.5926 g.
1 gal. = 8.34541 lb.
1 lb. av. = 27.679886 cu. in. H_2O at 4°C.
1 lb. av. = 7,000 grains
1 gal. = 58,417.87 grains
231 cu. in. = 1 gal. = 3,785.4162 g.

In converting from volume to weight, the specific gravity must also be used in the multiplier.

[1] Compiled by E. I. du Pont de Nemours & Co.

Table IV.—Interconversion Table for Units of Energy[1]

To convert from	Multiply by										
	B.t.u.	P.c.u.	Cal.	Ft.-lb.	Ft.-tons	Kg.-m.	Hp.-hr.	Kw.-hr.	Joules	Lb. C	Lb. H_2O
B.t.u.	1.00000	0.555556	0.251996	778.000	0.389001	107.563	$0.0_{3}3929$	$0.0_{3}2931$	1055.20	$0.0_{4}6876$	0.001031
P.c.u.	1.80000	1.00000	45.3593	1400.40	0.700202	193.613	$0.0_{3}7072$	$0.0_{3}5276$	1899.36	$0.0_{3}1238$	0.001855
Calories	3.96832	2.20462	1.00000	3091.36	1.54368	426.844	0.001559	0.001163	4187.37	$0.0_{3}2729$	0.004089
Ft.-lb.	0.001285	$0.0_{3}7141$	$0.0_{3}3239$	1.00000	0.000500	0.138255	$0.0_{6}5050$	$0.0_{6}3767$	1.35625	$0.0_{7}8840$	$0.0_{5}1325$
Ft.-tons	2.57069	1.428160	0.647804	2000.00	1.00000	276.511	0.001010	$0.0_{3}7535$	2712.59	$0.0_{3}1768$	0.002649
Kg.-m.	0.009297	0.005165	0.002343	7.23301	0.003617	1.00000	$0.0_{5}3653$	$0.0_{5}2725$	9.81009	$0.0_{6}6394$	$0.0_{5}9580$
Hp.-hr.	2544.990	0.141388	641.327	1980000	990.004	273747	1.00000	0.746000	2685473	0.175044	2.62261
Kw.-hr.	3411.57	1895.32	859.702	2654200	1327.10	366959	1.34041	1.00000	3599889	0.234648	3.51562
Joules	$0.0_{3}9477$	$0.0_{3}5265$	$0.0_{3}2388$	0.737311	$0.0_{3}3687$	0.101937	$0.0_{6}3724$	$0.0_{6}2778$	1.00000	$0.0_{7}6518$	$0.0_{6}9766$
Lb. C	14544.0	8080.00	3665.03	113150_{3}	5657.63	1564396	5.71434	4.26285	153470_{3}	1.00000	14.9876
Lb. H_2O	970.400	539.111	244.537	754971	377.487	104379	0.381270	0.284424	1023966	0.066744	1.00000

"P.c.u." refers to the "pound-centigrade unit." The ton used is 2,000 lb. "Lb. C" refers to pounds of carbon oxidized, 100% efficiency equivalent to the corresponding number of heat units. "Lb. H_2O" refers to pounds of water evaporated at 100°C. = 212°F. at 100% efficiency.

[1] Compiled by E. I. du Pont de Nemours & Co.

Table V.—Temperature Conversion Tables (*Albert Sauveur*)

Note.—The numbers in bold type refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit degrees to Centigrade degrees the equivalent temperature will be found in the left column, while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right.

Printed through the courtesy of Albert Sauveur, Cambridge, Mass.

−459.4 to −200			−190 to +8			9 to 36			37 to 64			65 to 92			93 to 280			290 to 560		
C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.
−273	**−459.4**		−123	**−190**	−310	−12.7	**9**	48.2	2.7	**37**	98.6	18.2	**65**	149.0	33.8	**93**	199.4	143	**290**	554
−268	**−450**		−118	**−180**	−292	−12.2	**10**	50.0	3.3	**38**	100.4	18.8	**66**	150.8	34.4	**94**	201.2	149	**300**	572
−262	**−440**		−112	**−170**	−274	−11.6	**11**	51.8	3.8	**39**	102.2	19.3	**67**	152.6	34.9	**95**	203.0	154	**310**	590
−257	**−430**		−107	**−160**	−256	−11.1	**12**	53.6	4.4	**40**	104.0	19.9	**68**	154.4	35.5	**96**	204.8	160	**320**	608
−251	**−420**		−101	**−150**	−238	−10.5	**13**	55.4	4.9	**41**	105.8	20.4	**69**	156.2	36.1	**97**	206.6	165	**330**	626
−246	**−410**		−96	**−140**	−220	−10.0	**14**	57.2	5.5	**42**	107.6	21.0	**70**	158.0	36.6	**98**	208.4	171	**340**	644
−240	**−400**		−90	**−130**	−202	−9.4	**15**	59.0	6.0	**43**	109.4	21.5	**71**	159.8	37.1	**99**	210.2	177	**350**	662
−234	**−390**		−84	**−120**	−184	−8.8	**16**	60.8	6.6	**44**	111.2	22.2	**72**	161.6	37.7	**100**	212.0	182	**360**	680
−229	**−380**		−79	**−110**	−166	−8.3	**17**	62.6	7.1	**45**	113.0	22.7	**73**	163.4	38	**100**	212	188	**370**	698
−223	**−370**		−73	**−100**	−148	−7.7	**18**	64.4	7.7	**46**	114.8	23.3	**74**	165.2	43	**110**	230	193	**380**	716
−218	**−360**		−68	**−90**	−130	−7.2	**19**	66.2	8.2	**47**	116.6	23.8	**75**	167.0	49	**120**	248	199	**390**	734
−212	**−350**		−62	**−80**	−112	−6.6	**20**	68.0	8.8	**48**	118.4	24.4	**76**	168.8	54	**130**	266	204	**400**	752
−207	**−340**		−57	**−70**	−94	−6.1	**21**	69.8	9.3	**49**	120.2	25.0	**77**	170.6	60	**140**	284	210	**410**	770
−201	**−330**		−51	**−60**	−76	−5.5	**22**	71.6	9.9	**50**	122.0	25.5	**78**	172.4	65	**150**	302	215	**420**	788
−196	**−320**		−46	**−50**	−58	−5.0	**23**	73.4	10.4	**51**	123.8	26.2	**79**	174.2	71	**160**	320	221	**430**	806
−190	**−310**		−40	**−40**	−40	−4.4	**24**	75.2	11.1	**52**	125.6	26.8	**80**	176.0	76	**170**	338	226	**440**	824
−184	**−300**		−34	**−30**	−22	−3.9	**25**	77.0	11.5	**53**	127.4	27.3	**81**	177.8	83	**180**	356	232	**450**	842
−179	**−290**		−29	**−20**	−4	−3.3	**26**	78.8	12.1	**54**	129.2	27.7	**82**	179.6	88	**190**	374	238	**460**	860
−173	**−280**		−23	**−10**	14	−2.8	**27**	80.6	12.6	**55**	131.0	28.2	**83**	181.4	93	**200**	392	243	**470**	878
−169	**−273**	−459.4	−17.7	**0**	32	−2.2	**28**	82.4	13.2	**56**	132.8	28.8	**84**	183.2	99	**210**	410	249	**480**	896
−168	**−270**	−454	−17.2	**1**	33.8	−1.6	**29**	84.2	13.7	**57**	134.6	29.3	**85**	185.0	100	**212**	413	254	**490**	914
−162	**−260**	−436	−16.6	**2**	35.6	−1.1	**30**	86.0	14.3	**58**	136.4	29.9	**86**	186.8	104	**220**	428	260	**500**	932
−157	**−250**	−418	−16.1	**3**	37.4	−0.6	**31**	87.8	14.8	**59**	138.2	30.4	**87**	188.6	110	**230**	446	265	**510**	950
−151	**−240**	−400	−15.5	**4**	39.2	0	**32**	89.6	15.6	**60**	140.0	31.0	**88**	190.4	115	**240**	464	271	**520**	968
−146	**−230**	−382	−15.0	**5**	41.0	0.5	**33**	91.4	16.1	**61**	141.8	31.5	**89**	192.2	121	**250**	482	276	**530**	986
−140	**−220**	−364	−14.4	**6**	42.8	1.1	**34**	93.2	16.6	**62**	143.6	32.1	**90**	194.0	127	**260**	500	282	**540**	1004
−134	**−210**	−346	−13.9	**7**	44.6	1.6	**35**	95.0	17.1	**63**	145.4	32.6	**91**	195.8	132	**270**	518	288	**550**	1022
−129	**−200**	−328	−13.3	**8**	46.4	2.2	**36**	96.8	17.7	**64**	147.2	33.3	**92**	197.6	138	**280**	536	293	**560**	1040

TABLE V.—TEMPERATURE CONVERSION TABLES (*Albert Sauveur*).—(*Continued*)

570 to 910			920 to 1250			1260 to 1600			1610 to 1950			1960 to 2300			2310 to 2650			2660 to 3000		
C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.	C.		F.
299	**570**	1058	493	**920**	1688	681	**1260**	2300	876	**1610**	2930	1069	**1960**	3560	1264	**2310**	4190	1460	**2660**	4820
304	**580**	1076	498	**930**	1706	686	**1270**	2318	882	**1620**	2948	1074	**1970**	3578	1270	**2320**	4208	1465	**2670**	4838
310	**590**	1094	504	**940**	1724	692	**1280**	2336	887	**1630**	2966	1080	**1980**	3596	1275	**2330**	4226	1471	**2680**	4856
315	**600**	1112	510	**950**	1742	697	**1290**	2354	893	**1640**	2984	1085	**1990**	3614	1281	**2340**	4244	1476	**2690**	4874
321	**610**	1130	515	**960**	1760	704	**1300**	2372	898	**1650**	3002	1093	**2000**	3632	1286	**2350**	4262	1483	**2700**	4892
326	**620**	1148	520	**970**	1778	708	**1310**	2390	904	**1660**	3020	1098	**2010**	3650	1292	**2360**	4280	1488	**2710**	4910
332	**630**	1166	526	**980**	1796	715	**1320**	2408	909	**1670**	3038	1104	**2020**	3668	1297	**2370**	4298	1494	**2720**	4928
338	**640**	1184	532	**990**	1814	719	**1330**	2426	915	**1680**	3056	1109	**2030**	3686	1303	**2380**	4316	1499	**2730**	4946
343	**650**	1202	538	**1000**	1832	726	**1340**	2444	920	**1690**	3074	1115	**2040**	3704	1308	**2390**	4334	1505	**2740**	4964
349	**660**	1220	538	**1000**	1832	734	**1350**	2462	926	**1700**	3092	1120	**2050**	3722	1315	**2400**	4352	1510	**2750**	4982
354	**670**	1238	543	**1010**	1850	737	**1360**	2480	931	**1710**	3110	1126	**2060**	3740	1320	**2410**	4370	1516	**2760**	5000
360	**680**	1256	549	**1020**	1868	741	**1370**	2498	937	**1720**	3128	1131	**2070**	3758	1326	**2420**	4388	1521	**2770**	5018
365	**690**	1274	554	**1030**	1886	748	**1380**	2516	942	**1730**	3146	1137	**2080**	3776	1331	**2430**	4406	1527	**2780**	5036
371	**700**	1292	560	**1040**	1904	752	**1390**	2534	948	**1740**	3164	1142	**2090**	3794	1337	**2440**	4424	1532	**2790**	5054
376	**710**	1310	565	**1050**	1922	760	**1400**	2552	953	**1750**	3182	1149	**2100**	3812	1342	**2450**	4442	1538	**2800**	5072
382	**720**	1328	571	**1060**	1940	765	**1410**	2570	959	**1760**	3200	1154	**2110**	3830	1348	**2460**	4460	1543	**2810**	5090
387	**730**	1346	576	**1070**	1958	771	**1420**	2588	964	**1770**	3218	1160	**2120**	3848	1353	**2470**	4478	1549	**2820**	5108
393	**740**	1364	582	**1080**	1976	776	**1430**	2606	970	**1780**	3236	1165	**2130**	3866	1359	**2480**	4496	1554	**2830**	5126
399	**750**	1382	587	**1090**	1994	782	**1440**	2624	975	**1790**	3254	1171	**2140**	3884	1364	**2490**	4514	1560	**2840**	5144
404	**760**	1400	593	**1100**	2012	787	**1450**	2642	981	**1800**	3272	1176	**2150**	3902	1371	**2500**	4532	1565	**2850**	5162
410	**770**	1418	598	**1110**	2030	793	**1460**	2660	986	**1810**	3290	1182	**2160**	3920	1376	**2510**	4550	1571	**2860**	5180
415	**780**	1436	604	**1120**	2048	798	**1470**	2678	992	**1820**	3308	1187	**2170**	3938	1382	**2520**	4568	1576	**2870**	5198
421	**790**	1454	609	**1130**	2066	804	**1480**	2696	997	**1830**	3326	1193	**2180**	3956	1387	**2530**	4586	1582	**2880**	5216
426	**800**	1472	615	**1140**	2084	809	**1490**	2714	1003	**1840**	3344	1198	**2190**	3974	1393	**2540**	4604	1587	**2890**	5234
432	**810**	1490	620	**1150**	2102	815	**1500**	2732	1008	**1850**	3362	1204	**2200**	3992	1398	**2550**	4622	1593	**2900**	5252
438	**820**	1508	626	**1160**	2120	820	**1510**	2750	1014	**1860**	3380	1209	**2210**	4010	1404	**2560**	4640	1598	**2910**	5270
443	**830**	1526	631	**1170**	2138	827	**1520**	2768	1019	**1870**	3398	1215	**2220**	4028	1409	**2570**	4658	1604	**2920**	5288
449	**840**	1544	637	**1180**	2156	831	**1530**	2786	1025	**1880**	3416	1220	**2230**	4046	1415	**2580**	4676	1609	**2930**	5306
454	**850**	1562	642	**1190**	2174	838	**1540**	2804	1030	**1890**	3434	1226	**2240**	4064	1420	**2590**	4694	1615	**2940**	5324
460	**860**	1580	648	**1200**	2192	842	**1550**	2822	1036	**1900**	3452	1231	**2250**	4082	1427	**2600**	4712	1620	**2950**	5342
465	**870**	1598	653	**1210**	2210	849	**1560**	2840	1041	**1910**	3470	1237	**2260**	4100	1432	**2610**	4730	1626	**2960**	5360
471	**880**	1616	659	**1220**	2228	853	**1570**	2858	1047	**1920**	3488	1242	**2270**	4118	1438	**2620**	4748	1631	**2970**	5378
476	**890**	1634	664	**1230**	2246	860	**1580**	2876	1052	**1930**	3506	1248	**2280**	4136	1443	**2630**	4766	1637	**2980**	5396
482	**900**	1652	677	**1240**	2264	864	**1590**	2894	1058	**1940**	3524	1253	**2290**	4154	1449	**2640**	4784	1642	**2990**	5414
487	**910**	1670	675	**1250**	2882	871	**1600**	2912	1063	**1950**	3542	1259	**2300**	4172	1454	**2650**	4802	1649	**3000**	5432

Table VI.—Chemical Engineers' Table of Equivalents

Chemical Equivalent.—The atomic weight divided by the valence.

Heat Capacity.—Specific heat is the number of B.t.u.'s required to raise 1 lb. of material 1°F. The molal heat capacity is the product of the specific heat and the molecular weight. Kopp's law: molal heat capacity of *solid* compounds is the sum of the atomic heat capacities of the constituent atoms. The atomic heat capacities may be taken as follows: C = 1.8; H = 2.3; B = 2.7; Si = 3.8; O = 4.0; P = 5.4; F = 5.4; all others = 6.2. Example: that of $CaCO_3 = 6.2 + 1.8 + 3 \times 4 = 20.0$ B.t.u. per °F. Law of Dulong and Petit: atomic heat capacity of *solid* elementary substances = 6.2; exceptions—C, B, P, and Si as above.

Heat of Vaporization.—B.t.u. required to vaporize 1 lb. of a substance. Molal heat of vaporization = heat of vaporization multiplied by the molecular weight. The molal heats of vaporization of similar liquids are approximately equal.

Humidity.—Absolute humidity is the pounds of water per pound of bone-dry air.

Mass Velocity.—$v = u\rho$

Moisture Per Cent.—

$$\text{Dry basis} = \frac{\text{wt. of water} \times 100}{\text{wt. of bone-dry material}}$$

$$\text{Wet basis} = \frac{\text{wt. of water} \times 100}{\text{bone-dry wt.} + \text{wt. of water}}$$

UNITS

Electrical.—(For d. c. only) $E = RI$. Power in watts $= I^2R$. Energy in watt-hours $= EIT$ when T is time in hours. 96,540 ampere-seconds = 1 faraday, which will theoretically deposit or liberate one chemical equivalent at an electrode.

Energy, Work, Heat.—1 B.t.u. = 252 cal. = 778 ft.-lb. = 0.293 watt-hour. 1 P.c.u. = 1.8 B.t.u. = 454 cal. 1 hp.hr. = 746 watt-hours = 2,545 B.t.u. = 1,980,000 ft.-lbs. 1 Cal. per gram, gram atom, or gram mol = 1 P.c.u. per lb., lb. atom, or lb. mol = 1.8 B.t.u. per lb., lb. atom, or lb. mol.

Hydrometers.—

Liquids lighter than water:

$$\text{Degrees Baumé} = \frac{140}{\text{sp. gr.}} - 130.$$

$$\text{Gravity A.P.I.} = \frac{141.5}{\text{sp. gr.}} - 131.5.$$

Liquids heavier than water:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{sp. gr.}}$$

$$\text{Degrees Twaddell} = \frac{\text{sp. gr.} - 1}{0.005}$$

Linear.—1 in. = 25.4 mm. = 2.54 cm.

Mass.—$M = \frac{\text{lb.}}{32.2}$

Mol.—Molecular weight of a substance expressed in units of weight.

Power.—*Rate of doing work:* 1 hp. = 746 watts = 33,000 ft.-lb. per minute = 42.4 B.t.u. per minute.

Pressure.—1 atmosphere = 29.92 in. of mercury = 760 mm. of mercury = 14.7 lb. per sq. in. = 33.9 ft. of water = 1,033 g. per sq. cm.

Temperature.—1°C. or K. (Kelvin) = 1.8°F. or R. (Rankine) = 0.8°. Ré (Réaumur). Freezing point of water = 0°C. = 273°K. = 32°F. = 460 + 32 or 492°R. = 0°Ré. 0°F. = 460°R.

Viscosity.—100 centipoises = 1 poise = 1 g. per sec.-cm. = 0.0672 lb. per sec.-ft. Kinematic viscosity $= \frac{\mu}{\rho}$.

Volume.—1 cu. ft. = 7.48 gal. 1 gal. = 231 cu. in. = 3,785 c.c.

Weight.—1 lb. = 453.6 grams = 7,000 grains avoirdupois.

GENERAL INFORMATION

Centrifugal Force.— $F = 0.000341\ WRN^2$ lb.

Combustion.—These major combustion reactions are all reversible:

$$\begin{aligned}
C + O_2 &= CO_2 + 97{,}000 \text{ cal.}\\
CO_2 + C &= 2CO - 39{,}000 \text{ cal.}\\
2C + O_2 &= 2CO + 58{,}000 \text{ cal.}\\
2CO + O_2 &= 2CO_2 + 136{,}000 \text{ cal.}\\
2\,H_2 + O_2 &= 2H_2O + 136{,}000 \text{ cal.}\\
H_2O + C &= CO + H_2 - 39{,}300 \text{ cal.}\\
2H_2O + C &= CO_2 + 2H_2 - 39{,}600 \text{ cal.}\\
CO + H_2O &= CO_2 + H_2 - 300 \text{ cal.}
\end{aligned}$$

The equilibrium of the gases above the bed of a gas producer is $0.096L = \frac{(CO_2)\,(H_2)}{(CO)\,(H_2O)}$, when L is depth of active fuel bed and volumes of gases are in terms of 100 volumes of dry gas.

Evaporation.—The pounds of water evaporated in evaporators per pound of steam is approximately $0.85n$, where n is the number of effects.

Flow of Fluids.—Venturi meter; $\sqrt{(u_2)^2 - (u_1)^2} = 0.98\sqrt{2g\Delta H}$
With a sharp-edged orifice use 0.61 instead of 0.98.
Pitot tube; $u = \sqrt{2g\Delta H}$.

Flow of Heat.—By conduction $Q/\Theta = U\Delta TA$

The over-all coefficient $$U = \frac{1}{\frac{L_1}{K_1A_1} + \frac{L_2}{K_2A_2} + \frac{L_3}{K_3A_3} + \text{etc.}}$$

When heat flows through a fluid film substitute $1/h$ for L/K as h is the film coefficient. The value of h for low pressure condensing steam is often taken as 2,000. The equation for water flowing in turbulent motion in horizontal pipes is:

$$h = \frac{0.00486(1 + 0.010t)(G^{0.8})}{D^{0.2}}.$$

Gas Laws.—Volume per cent = mol per cent = pressure per cent. A pound mol of any gas occupies 359 cu. ft. at 32°F. and 1 atmosphere (S.C.).

$$V_2 = V_1\frac{P_1T_2}{P_2T_1}.$$

The apparent molecular weight of air may be taken as 29.

TABLE VII.—OVER-ALL COEFFICIENTS OF HEAT TRANSFER

Hot medium	Cool medium	u			Typical device
Liquid cooling	Liquid heating	20	60	350	Liquid heat exchangers
	Gas or air heating	1	5	12	Hot-water radiators. Air-cooled pipe coils
	Liquid boiling	10	20	100	Tank with hot-water coil evaporators
Gas cooling	Liquid heating	1	4	10	Economizers and air coolers
	Gas or vapor heating	1	4	10	Steam superheaters
	Liquid boiling	1	4	10	Steam boilers, refrigeration coils (direct expansion)
Vapor condensing	Liquid heating	10	200	1,000	Steam condensers. Feed water heaters
	Gas heating	1	4	10	Steam radiators and pipe coils
	Liquid boiling	50	500	1,000	Evaporators

TABLE VIII.—PROPERTIES OF WATER AND SATURATED STEAM

Temperature, degrees Fahrenheit	Temperature, degrees Centigrade	Absolute pressure, pounds per square inch[1]	Latent heat of evaporation, B.t.u. per pound[1]	Specific volume, cubic feet per pound[1]	Density of liquid water, pounds per cubic foot	Viscosity of liquid water centipoises[2]
32	0.00	0.0887	1,073.4	3,301	62.42	1.794
35	1.67	0.1000	1,071.8	2,946	62.43	1.692
40	4.44	0.1217	1,069.1	2,445	62.43	1.546
45	7.22	0.1475	1,066.3	2,037.2	62.42	1.420
50	10.00	0.1780	1,063.6	1,704.8	62.42	1.310
55	12.78	0.2140	1,060.9	1,431.8	62.40	1.213
60	15.56	0.2561	1,058.2	1,208.0	62.37	1.129
65	18.33	0.3054	1,055.4	1,022.7	62.34	1.052
70	21.11	0.3628	1,052.7	869.0	62.30	0.982
75	23.89	0.4295	1,050.0	740.9	62.26	0.919
80	26.67	0.5067	1,047.3	633.8	62.22	0.862
85	29.44	0.5960	1,044.6	543.8	62.17	0.810
90	32.22	0.6980	1,041.8	468.5	62.11	0.764
95	35.00	0.8149	1,039.1	404.9	62.06	0.721
100	37.78	0.9487	1,036.3	350.8	62.00	0.682
105	40.56	1.1009	1,033.5	305.0	61.93	0.647
110	43.44	1.274	1,030.8	265.8	61.86	0.616
115	46.11	1.470	1,027.9	232.3	61.79	0.586
120	48.89	1.692	1,025.1	203.6	61.71	0.559
125	51.67	1.941	1,022.2	178.9	61.63	0.535
130	54.44	2.221	1,019.4	157.64	61.55	0.511
135	57.22	2.536	1,016.5	139.17	61.46	0.490
140	60.00	2.887	1,013.6	123.22	61.38	0.470
145	62.78	3.280	1,010.6	109.31	61.29	0.451
150	65.56	3.716	1,007.7	97.23	61.20	0.433
155	68.33	4.201	1,004.7	86.66	61.10	0.417
160	71.11	4.739	1,001.8	77.40	61.00	0.401
165	73.89	5.334	998.8	69.28	60.90	0.386
170	76.67	5.990	995.8	62.14	60.80	0.372
175	79.44	6.716	992.8	55.82	60.69	0.359
180	82.22	7.510	989.8	50.28	60.58	0.347
185	85.00	8.382	986.8	45.36	60.47	0.336
190	87.78	9.336	983.8	41.01	60.36	0.325
195	90.56	10.385	980.8	37.12	60.24	0.315
200	93.33	11.525	977.7	33.67	60.12	0.305
205	96.11	12.771	974.6	30.59	60.00	0.295
210	98.89	14.123	971.5	27.83	59.88	0.287
212	100.00	14.696	970.2	26.82	59.83	0.284
215	101.67	15.594	968.2	25.37	59.76	
220	104.44	17.188	965.1	23.16		
225	107.22	18.91	961.8	21.17		
230	110.00	20.78	958.6	19.388		
235	112.22	22.80	955.2	17.779		
240	115.56	24.97	952.0	16.324		
245	118.33	27.31	948.6	15.011		

[1] Condensed from Keenan, "Steam Tables," *A.S.M.E.*, 1930.
[2] Calculated by Badger and McCabe from data in "International Critical Tables."

TABLE VIII.—PROPERTIES OF WATER AND SATURATED STEAM.—(*Continued*)

Temperature, degrees Fahrenheit	Temperature, degrees Centigrade	Absolute pressure, pounds per square inch[1]	Latent heat of evaporation, B.t.u. per pound[1]	Specific volume, cubic feet per pound[1]	Density of liquid water, pounds per cubic foot	Viscosity of liquid water, centipoises[2]
250	121.11	29.82	945.2	13.824		
260	126.67	35.43	938.4	11.762		
270	132.22	41.85	931.4	10.061		
280	137.78	49.20	924.2	8.644		
290	143.33	57.55	917.0	7.459		
300	148.89	67.01	909.6	6.464		
310	154.44	77.68	902.1	5.623		
320	160.00	89.65	894.4	4.910		
330	165.56	103.03	886.5	4.303		
340	171.11	117.99	878.5	3.784		
350	176.67	134.62	870.2	3.338		
360	182.22	153.01	861.7	2.954		
370	187.78	173.33	853.0	2.622		
380	193.33	195.70	844.1	2.333		
390	198.89	220.29	834.9	2.0816		
400	204.44	247.25	825.5	1.8608		

[1] Condensed from Keenan, "Steam Tables," *A.S.M.E.*, 1930.

[2] Calculated by Badger and McCabe from data in "International Critical Tables."

TABLE IX.—WATER EQUIVALENTS

Gallons per minute	Cubic feet per minute	Gallons per hour	Gallons per 24 hr.	Barrels[1] per minute	Barrels per 24 hr.
10	1.337	600	14,000	0.24	342.8
15	2.005	900	21,600	0.36	514.3
20	2.673	1,200	28,800	0.48	685.7
25	3.342	1,500	36,000	0.59	857
30	4.001	1,800	43,200	0.71	1,028
40	5.348	2,400	57,600	0.95	1,371
50	6.684	3,000	72,000	1.19	1,714
60	8.021	3,600	86,400	1.43	2,057
70	9.357	4,200	100,800	1.66	2,400
80	10.694	4,800	115,200	1.90	2,742
90	12.031	5,400	129,600	2.14	3,085
100	13.368	6,000	144,000	2.38	3,428
125	16.710	7,500	180,000	2.98	4,286
150	20.052	9,000	216,000	3.57	5,143
175	23.394	10,500	252,000	4.16	6,000
200	26.736	12,000	288,000	4.76	6,857
250	33.421	15,000	360,000	5.95	8,570
300	40.104	18,000	432,000	7.14	10,284
400	53.472	24,000	576,000	9.52	13,723
500	66.842	30,000	720,000	11.9	17,143
600	80.208	36,000	864,000	14.3	20,570
800	106.94	48,000	1,152,000	19.05	27,387
1,000	133.68	60,000	1,440,000	23.8	34,284
1,500	200.52	90,000	2,160,000	35.7	51,427
2,000	267.36	120,000	2,880,000	47.64	68,568
2,500	334.21	150,000	3,600,000	59.52	85,704
3,000	401.04	180,000	4,320,000	71.43	102,840

[1] Forty-two gallons.

To determine the velocity in feet per minute necessary to discharge a given volume of water in a given time, multiply the number of cubic feet of water by 144 and divide the product by the area of the pipe in inches.

To find the theoretical velocity in feet per second due to any head, multiply the square root of the head in feet by 8.02.

To determine the area of a required pipe, the volume and velocity of water being given, multiply the number of cubic feet of water by 144 and divide the product by the velocity in feet per minute.

Table X.—Pressures in Pounds per Square Inch, Corresponding to Heads of Water in Feet

Head, feet	0	1	2	3	4	5	6	7	8	9
0		0.433	0.866	1.299	1.732	2.165	2.598	3.031	3.464	3.897
10	4.330	4.763	5.196	5.629	6.062	6.495	6.928	7.361	7.794	8.227
20	8.660	9.093	9.526	9.959	10.392	10.825	11.258	10.691	12.124	12.557
30	12.990	13.423	13.856	14.289	14.722	15.155	15.588	16.021	16.454	16.887
40	17.320	17.753	18.186	18.619	19.052	19.485	19.918	20.351	20.784	21.217
50	21.650	22.983	22.516	22.949	23.382	23.815	24.248	24.681	25.114	25.547
60	25.980	26.413	26.846	27.279	27.712	28.145	28.578	29.011	29.444	29.877
70	30.310	30.743	31.176	31.609	32.042	32.475	32.908	33.341	33.774	34.207
80	34.640	35.073	35.506	35.939	36.372	36.805	37.238	37.671	38.104	38.537
90	38.970	39.403	39.836	40.269	40.702	41.135	40.568	42.001	42.436	42.867

Table XI.—Contents of Pipes and Cylindrical Tanks, with Horizontal Axis and Flat Ends, per Foot of Length for Any Depth of Liquid[1]

h = Depth of liquid inches	d = diameter of tank, inches									
	12		18		24		30		36	
	Gal.	Cu. ft.	Gal.	Cu. ft.	Gal.	Cu. ft.	Gal.	Cu. ft.	Gal.	Cu. ft.
2	0.64	0.0860	0.80	0.1072	0.93	0.1244	1.05	0.1400	1.15	0.154
4	1.73	0.2317	2.18	0.2920	2.57	0.3440	2.90	0.3878	3.21	0.429
6	2.94	0.3927	3.85	0.5149	4.59	0.6140	5.23	0.6988	5.80	0.775
8	4.14	0.5537	5.67	0.7578	6.85	0.9152	7.85	1.049	8.75	1.17
10	5.23	0.6994	7.55	1.009	9.26	1.238	10.72	1.432	12.0	1.60
12	5.87	0.7854	9.38	1.252	11.75	1.571	13.72	1.833	15.4	2.03
14	.....	.....	11.04	1.476	14.24	1.903	16.82	2.248	19.0	2.54
16	.....	.....	12.43	1.659	16.65	2.226	19.90	2.660	22.6	3.02
18	.....	.....	13.22	1.767	18.91	2.527	23.00	3.075	26.4	3.53
20	.....	.....	.....	.....	20.93	2.797	26.00	3.476	29.6	3.95
22	.....	.....	.....	.....	22.57	3.017	28.85	3.859	33.4	4.46
24	.....	.....	.....	.....	23.50	3.1416	31.49	4.209	37.4	5.00
26	.....	.....	.....	.....	.....	.....	33.82	4.521	40.4	5.40
28	.....	.....	.....	.....	.....	.....	35.67	4.768	43.7	5.84
30	.....	.....	.....	.....	.....	.....	36.72	4.908	46.6	6.23
32	.....	.....	.....	.....	.....	.....	.....	.....	49.1	6.55
34	.....	.....	.....	.....	.....	.....	.....	.....	51.2	6.85
36	.....	.....	.....	.....	.....	.....	.....	.....	52.9	7.07
38										
40										
42										
44										
46										
48										
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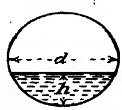

Formulas for determination of approximate capacity of horizontal cylindrical tanks for any depth. Given:—diameter of tank d and height of segment h.
To find area of segment

when $h = 0$ to $\frac{1}{4}d$; area $= h\sqrt{1.766dh - h^2}$

when $h = \frac{1}{4}d$ to $\frac{1}{2}d$; area $= h\sqrt{0.017d^2 + 1.7dh - h^2}$

1 cu. ft. = 7.4805 U. S. gal.

[1] Reprinted from the "Piping Handbook," by Walker and Crocker.

TABLE XII.—CONTENTS OF PIPES OR CYLINDRICAL TANKS OF VARIOUS DIAMETERS AND ONE FOOT HIGH

Diameter, inches	Volume, gallons	Diameter, inches	Volume, gallons
⅜	0.005	4½	0.826
½	0.010	5	1.02
¾	0.023	5½	1.23
1	0.047	6	1.47
1¼	0.064	7	2.00
1½	0.092	8	2.61
2	0.163	9	3.30
2½	0.255	10	4.08
3	0.367	11	4.93
3½	0.500	12	4.87
4	0.652		

TABLE XIII.—STEEL-PIPE TABLES[1]
(Standard and extra-heavy pipe)

Nominal size, inches	Diameter, actual external	Standard: Diameter, actual internal	Standard: Internal area, sq. in.	Standard: Capacity, gal. per 100 ft.	Standard: G.p.m. at 1 ft. per sec. velocity	Standard: Nominal weight, lb. per ft.	Standard: Lap weld[2]	Standard: Butt weld[2]	Extra heavy: Diameter, actual internal	Extra heavy: Internal area, sq. in.	Extra heavy: Capacity, gal. per 100 ft.	Extra heavy: G.p.m. at 1 ft. per sec. velocity	Extra heavy: Nominal weight, lb. per ft.	Extra heavy: Lap weld[2]	Extra heavy: Butt weld[2]
1/8	0.405	0.27	0.06	0.295	0.18	0.24		2,500	0.22	0.04	0.189	0.11	0.31		3,500
1/4	0.540	0.36	0.10	0.541	0.32	0.42			0.30	0.07	0.372	0.22	0.54		
3/8	0.675	0.49	0.19	0.993	0.60	0.57		1,500	0.42	0.14	0.730	0.44	0.74		2,500
1/2	0.840	0.62	0.30	1.579	0.95	0.85			0.55	0.23	1.216	0.73	1.09		
3/4	1.050	0.82	0.53	2.770	1.66	1.13			0.74	0.43	2.246	1.35	1.47		2,000
1	1.315	1.05	0.86	4.490	2.69	1.68			0.96	0.72	3.732	2.24	2.17		
1¼	1.660	1.38	1.50	7.770	4.46	2.27		1,000	1.28	1.28	6.664	4.00	3.00	2,000	1,500
1½	1.900	1.61	2.04	10.58	6.35	2.72			1.50	1.77	9.180	5.51	3.63		
2	2.375	2.07	3.36	17.43	10.5	3.65	1,250	750	1.94	2.95	15.34	9.20	5.02	1,500	1,250
2½	2.875	2.47	4.79	24.87	14.9	5.79			2.32	4.24	22.02	13.2	7.66		
3	3.500	3.07	7.39	38.40	23.0	7.58	1,000		2.90	6.61	34.31	20.6	10.25		
3½	4.000	3.55	9.89	51.36	30.8	9.11			3.36	8.89	46.17	27.7	12.51		
4	4.500	4.03	12.73	66.13	39.7	10.79	750		3.83	11.50	59.72	35.8	14.98	1,250	
5	5.563	5.05	20.01	103.9	62.4	14.62			4.81	18.19	94.51	56.7	20.78		
6	6.625	6.07	28.89	150.1	90.0	18.97			5.76	26.07	135.4	81.2	28.57		
8	8.625	7.98	50.02	259.9	156	28.55	650		7.63	45.66	237.2	142	43.34	1,000	
8	8.625	8.07	51.16	265.8	159	24.69									
9	9.625	8.94	62.79	326.2	195	33.91			8.63	58.43	303.5	182	48.73		
10	10.75	10.02	78.85	409.6	246	40.48	500		9.75	74.66	387.8	233	54.74	750	
10	10.75	10.14	80.69	419.2	252	34.24									
10	10.75	10.19	81.58	423.8	255	31.20									
12	12.75	12.00	113.1	587.5	353	49.56			11.75	108.4	563.3	338	65.42		
12	12.75	12.09	114.8	596.4	358	43.77	450								
14	15.00	14.25	159.5	828.5	497	58.57			14.00	153.9	799.7	480	77.43	600	

[1] After Baldwin-Southwark Corp.

[2] Maximum service pressure, 16 per sq. in.; if subject to severe shock, reduce to 75 per cent.

TABLE XIII.—STEEL-PIPE TABLES.[1]—(*Continued*)
(Double-extra-heavy pipe and seamless tubes)

Nominal size, inches	Diameter, actual external	Double extra heavy: Diameter, actual internal	Internal area, sq. in.	Capacity, gal. per 100 ft.	G.p.m. at 1 ft. per sec. velocity	Nominal weight, lb. per ft.	Lap weld[2]	Butt weld[2]	Seamless tubes: Diameter, actual internal	Internal area, sq. in.	Capacity, gal. per 100 ft.	G.p.m. at 1 ft. per sec. velocity	Nominal weight, lb. per ft.	
½	0.840	0.25	0.05	0.259	0.16	1.71		5,000	0.25	0.05	0.259	0.16	1.71	
¾	1.050	0.43	0.15	0.768	0.46	2.44		4,000	0.43	0.15	0.768	0.46	2.44	6,000
1	1.315	0.60	0.28	1.464	0.88	3.66			0.60	0.28	1.464	0.88	3.66	
1¼	1.660	0.90	0.63	3.276	1.96	5.21	4,000	3,000	0.90	0.63	3.276	1.96	5.21	
1½	1.900	1.10	0.95	4.937	2.96	6.41			1.10	0.95	4.937	2.96	6.41	
2	2.375	1.50	1.77	9.217	5.53	9.03	3,500	2,500	1.50	1.77	9.217	5.53	9.03	4,000
2½	2.875	1.77	2.46	12.80	7.68	13.70			1.77	2.46	12.80	7.68	13.70	
3	3.500	2.30	4.16	21.58	13.0	18.58	3,000		2.30	4.16	21.58	13.0	18.58	3,500
3½	4.000	2.73	5.85	30.36	18.2	22.85			2.73	5.85	30.36	18.2	22.85	
4	4.500	3.15	7.80	40.54	24.3	27.54	2,500		3.15	7.80	40.54	24.3	27.54	3,000
5	5.563	4.06	12.97	67.35	40.4	38.55			4.06	12.97	67.35	40.4	38.55	
6	6.625	4.90	18.84	97.84	58.7	53.16			4.90	18.84	97.84	58.7	53.16	2,500
8	8.625	6.88	37.12	192.8	116	72.42	2,000		6.88	37.12	192.8	116	72.42	2,000

[1] After Baldwin-Southwark Corp.
[2] Maximum service pressure, pound per square inch; if subject to severe shock, reduce to 75 per cent.

Bursting Pressure.—May be calculated for cold water according to Barlow's formula:

$$P = 2ft/D$$

where P = lb. per sq. in.; t = wall thickness, in.; D = outside diameter, in.; and f = 41,000 for butt-weld steel, 52,000 for lap-weld steel and 62,000 for seamless steel.

TABLE XIV.—STANDARD DIMENSIONS OF CAST-IRON FLANGED PIPE

Nominal diameter, inches	Diameter of flange, inches	Diameter of bolt circle, inches	Number of bolts	Diameter of bolts, inches	Class A 100 ft. head 43 lb. pressure				Class B 200 ft. head 86 lb. pressure				Class C 300 ft. head 130 lb. pressure				Class D 400 ft. head 173 lb. pressure			
					Thickness, inches	Weight, pounds per			Thickness, inches	Weight, pounds per			Thickness, inches	Weight, pounds per			Thickness, inches	Weight, pounds per		
						Foot	Length	Single flange		Foot	Length	Single flange		Foot	Length	Single flange		Foot	Length	Single flange
3	7.50	6.00	4	⅝	0.39	13.0	168	5.8	.42	14.6	188	6.3	.45	15.5	199	6.6	.48	16.4	211	7.1
4	9.00	7.50	8	⅝	0.42	18.0	234	9.0	.45	20.1	259	9.1	.48	21.3	275	9.7	.52	22.8	295	10.4
6	11.00	9.50	8	¾	0.44	27.9	358	11.8	.48	31.1	398	12.3	.51	32.9	421	12.8	.55	35.3	451	13.7
8	13.50	11.75	8	¾	0.46	38.7	498	16.9	.51	42.7	549	18.2	.56	48.0	614	19.0	.60	51.2	654	20.1
10	16.00	14.25	12	⅞	0.50	51.9	671	23.9	.57	58.8	759	26.6	.62	65.5	840	27.3	.68	71.4	916	29.6
12	19.00	17.00	12	⅞	0.54	67.0	876	35.8	.62	76.4	998	40.4	.68	85.4	1109	42.0	.75	93.7	1216	45.6
14	21.00	18.75	12	1	0.57	82.3	1070	41.4	.66	94.7	1231	47.3	.74	108.1	1397	49.6	.82	119.2	1539	54.5
16	23.50	21.25	16	1	0.60	98.8	1290	52.5	.70	114.6	1495	60.1	.80	133.3	1727	63.9	.89	147.5	1910	70.2
18	25.00	22.75	16	1⅛	0.64	118.3	1528	54.5	.75	137.8	1779	62.5	.87	162.4	2083	66.9	.96	178.4	2287	73.4

Table XV.—Specific Gravities and Weights of Materials
(Solids and liquids referred to water at 4°C. Gases referred to air at 0° and 760 mm. pressure. Weights are average)

Substance	Specific gravity	Weight, lb. per cu. ft.
Bituminous Substances		
Asphaltum	1.1–1.5	81
Coal, anthracite	1.4–1.7	97
Coal, bituminous	1.2–1.5	84
Coal, lignite	1.1–1.4	78
Coal, peat, turf, dry	0.65–0.85	47
Coal, charcoal, pine	0.28–0.44	23
Coal, charcoal, oak	0.47–0.57	33
Coal, coke	1.0–1.4	75
Graphite	1.9–2.3	131
Graphite, flour	....	28
Graphite, flake	....	40
Paraffin	0.87–0.91	56
Petroleum	0.87	54
Petroleum, refined	0.79–0.92	50
Petroleum, benzine	0.73–0.75	46
Petroleum, gasoline	0.66–0.69	42
Pitch	1.07–1.15	69
Tar, bituminous	1.20	75
Building Materials		
Ashes, cinders, dry	....	35–40
Ashes, cinders, wet	....	40–45
Cinder	....	40
Cement clinker	....	95
Cement, Portland, loose	....	90
Cement, Portland, set	2.7–3.2	183
Fine dust	....	110–125
Fly ash	....	30–45
Glass, common	....	156
Glass, plate	....	161
Glass, crystal	....	184
Glass, cullets	....	90
Lime, gypsum, loose	....	53–64
Lime, unslaked	....	95
Lime, hydrated	....	20–45
Mortar, set	1.4–1.9	103
Slags, bank slag	....	67–72
Slags, bank screenings	....	98–117
Slags, machine slag	....	96
Slags, slag sand	....	49–55
Coal and Coke, Piled		
Coal, anthracite	....	47–58
Coal, bituminous, lignite	....	40–54
Coal, peat, turf	....	20–26
Coal, steam	....	50
Coal, pulverized	....	32–35
Coal, charcoal	....	10–14
Coke, breeze	....	23–32
Coke, refiners	....	35–40
Earth, Etc., Excavated		
Clay, dry	....	63
Clay, damp, plastic	....	110
Clay and gravel, dry	....	100
Earth, dry, loose	....	76
Earth, dry, packed	....	95
Earth, moist, loose	....	78
Earth, moist, packed	....	96
Earth, mud, flowing	....	108
Earth, mud, packed	....	115
Limestone	....	80–85
Marl	....	79
Earth, Etc., Excavated (*Continued*)		
Sandstone	....	90
Shale	....	105
Sand, gravel, dry, loose	....	90–105
Sand, gravel, dry, packed	....	100–120
Sand, gravel, dry, wet	....	118–120
Slate	....	80–90
Traprock	....	97–107
Excavation in Water		
Sand or gravel	....	6
Sand or gravel and clay	....	
Clay	....	80
River mud	....	90
Soil	....	70
Stone riprap	....	65
Liquids		
Acid, acetic, 90 %	1.061	66.3
Acid, fluoric, 58 %	1.20	75
Acids, muriatic 40 %	1.20	75
Acid, nitric, 35 %	1.22	76
Acids, nitric 91 %	1.50	94
Acid, phosphoric, 72 %	1.557	97.2
Acids, sulfuric 87 %	1.80	112
Acid, sulfuric, 97 %	1.84	115
Alcohol, 100 %	0.79	49
Alcohol, proof	....	59
Benzine	0.85	50
Lye, soda 66 %	1.70	106
Oil, linseed	0.94	59
Oils, vegetable	0.91–0.94	58
Oil, olive	0.92	58
Oils, mineral, lubricants	0.90–0.93	57
Tar	1.0	62.4
Water, 4°C. max. density	1.0	62.428
Water, 100°C.	0.9584	59.830
Water, ice	0.88–0.92	56
Water, snow, fresh fallen	0.125	8
Water, sea water	1.02–1.03	64
Ashlar Masonry		
Granite, syenite, gneiss	2.3–3.0	165
Limestone, marble	2.3–2.8	160
Sandstone, bluestone	2.1–2.4	140
Brick Masonry		
Pressed brick	2.2–2.3	140
Common brick	1.8–2.0	120
Soft brick	1.5–1.7	100
Concrete Masonry		
Cement, stone, sand	2.2–2.4	144
Cement, slag, etc.	1.9–2.3	130
Cement, cinder, etc.	1.5–1.7	100
Mortar Rubble Masonry		
Granite, syenite, gneiss	2.2–2.8	155
Limestone, marble	2.2–2.6	150
Sandstone, bluestone	2.0–2.2	130

TABLE XV.—SPECIFIC GRAVITIES AND WEIGHTS OF MATERIALS.—(*Continued*)

Substance	Specific gravity	Weight, lb. per cu. ft.
Dry Rubble Masonry		
Granite, syenite, gneiss	1.9–2.3	130
Limestone, marble	1.9–2.1	125
Sandstone, bluestone	1.8–1.9	110
Gases		
Air, 0°C., 760 mm	1.0	0.08071
Ammonia	0.5920	0.0478
Carbon dioxide	1.5291	0.1234
Carbon monoxide	0.9673	0.0781
Gas, illuminating	0.35–0.45	0.028–.036
Gas, natural	0.47–0.48	0.038–.039
Hydrogen	0.0693	0.00559
Nitrogen	0.9714	0.0784
Oxygen	1.1056	0.0892
Metals, Alloys, Ores		
Aluminum, cast-hammered	2.55–2.75	165
Aluminum, bronze	7.7	481
Babbitt	....	454
Beryllium	....	120
Bismuth	....	611
Brass, cast-rolled	8.4–8.7	534
Bronze, 7.9 to 14% Sn	7.4–8.9	509–541
Chromium	....	428
Copper, cast-rolled	8.8–9.0	556
Duralium	....	180
Gold, cast-hammered	19.25–19.3	1205
Iron, cast, pig	7.2	450
Iron, wrought	7.6–7.9	485
Iron, steel	7.8–7.9	490
Iron, spiegeleisen	7.5	468
Iron, ferrosilicon	6.7–7.3	437
Iron slag	2.5–3.0	172
Lead	11.37	710
Magnesium	....	109
Manganese	7.2–8.0	475
Mercury	13.6	849
Nickel	8.9–9.2	565
Nickel, Monel metal	8.8–9.0	556
Platinum, cast-hammered	21.1–21.5	1330
Silver, cast-hammered	10.4–10.6	656
Spelter	....	437.5
Sodium	....	61
Tin, cast-hammered	7.2–7.5	459
Tin ore, cassiterite	6.4–7.0	418
Tungsten	....	1224
Vanadium	....	343
Zinc, cast-rolled	6.9–7.2	440
Zinc ore, blende	3.9–4.2	253
Minerals		
Apatite	....	200
Asbestos, shredded	....	20–25
Barytes	....	180
Basalt	2.7–3.2	184
Bauxite	2.55	159
Bauxite, crushed	....	75–80
Calcite	....	170
Clay, marl	1.8–2.6	137
Copper ore	....	262
Dolomite	2.9	181
Feldspar	2.5	159
Feldspar, ground	....	75–80
Fluospar	....	110
Fuller's earth, raw	....	35–40
Minerals (*Continued*)		
Fuller's earth, 35% oil	....	60–65
Galena	....	465
Gneiss, serpentine	2.4–2.7	159
Granite, syenite	2.5–3.1	175
Greenstone, trap	2.8–3.2	187
Gypsum, alabaster	2.3–2.8	159
Gypsum, crushed	....	55–60
Hornblende	3.0	187
Iron ore, hematite	5.2	325
Iron ore, hematite in bank	....	160–180
Iron ore, hematite loose	....	130–160
Iron ore, limonite	3.6–4.0	237
Iron ore, magnetite	4.9–5.2	315
Limestone, marble	2.5–2.8	165
Magnesite	3.0	187
Mica, flake	....	17–22
Phosphate rock, apatite	3.2	200
Porphyry	2.6–2.9	172
Pumice, natural	0.37–0.90	40
Pyrites	....	262
Pyrolusite	....	259
Quartz, flint	2.5–2.8	165
Sandstone, bluestone	2.2–2.5	147
Shale, slate	2.7–2.9	175
Soapstone, talc	2.6–2.8	169
Stone, Quarried, Piled		
Basalt, granite, gneiss	....	96
Limestone, marble, quartz	....	95
Porcelain	....	145
Sandstone	....	82
Shale	....	92
Greenstone, hornblende	....	107
Timber, U. S. Seasoned		
Ash, white, red	0.62–0.65	40
Birchwood	0.65	41
Cedar, white, red	0.32–0.38	22
Cherry	0.70	44
Chestnut	0.66	41
Cypress	0.48	30
Fir, Douglas spruce	0.51	32
Fir, eastern	0.40	25
Elm, white	0.72	45
Hemlock	0.42–0.52	29
Hickory	0.74–0.84	49
Lignum vitae	0.66–1.33	41–83
Locust	0.73	46
Maple, hard	0.68	43
Maple, white	0.53	33
Oak, chestnut	0.86	54
Oak, live	0.95	59
Oak, red, black	0.65	41
Oak, white	0.74	46
Pine, Oregon	0.51	32
Pine, red	0.48	30
Pine, white	0.41	26
Pine, yellow, long-leaf	0.70	44
Pine, yellow, short-leaf	0.61	38

Table XV.—Specific Gravities and Weights of Materials.—(*Continued*)

Substance	Specific gravity	Weight, lb. per cu. ft.
Timber, U. S. Seasoned (*Continued*)		
Poplar	0.48	30
Redwood, California	0.42	26
Spruce, white, black	0.40–0.46	27
Sycamore	0.59	37
Walnut, black	0.61	38
Walnut, white	0.41	26
Moisture Contents:		
Seasoned timber 15 to 20%		
Green timber up to 50%		
Agricultural Products		
Barley	...	38
Beans	...	48
Beans, castor	...	36
Beans, soy	...	45–50
Bones, crushed	...	35–40
Bone meal	...	55–60
Borax	...	109
Bran	...	16
Brewer's grain, spent, wet	...	55–60
Brewer's grain, spent, dried	...	25–30
Buckwheat	...	42
Butter	...	59
Cocoa	...	30–35
Cocoa beans	...	35–40
Coffee	...	40–42
Cork, ground	...	12
Corn, shelled	...	45
Corn, grits	...	42–43
Cornmeal	...	40
Cottonseed, dry	...	25
Cottonseed cake	...	40–45
Cottonseed hulls	...	12
Cottonseed meal	...	35–40
Fats	...	58
Flaxseed	...	45
Flaxseed cake	...	44–50
Flaxseed meal	...	25
Flour	...	28
Flour, pressed	...	47
Hay, baled	...	24
Hominy	...	37
Lard	...	59
Leather	...	59
Malt, dry, crushed	...	20–22
Malt, dry, whole	...	27–30
Malt, wet	...	60–65
Malt meal	...	36–40
Milk, dried, flake	...	36
Milk, malted	...	27
Oats	...	26
Oleomargarine	...	59
Peanuts, shelled	...	20–25
Peanuts, unshelled	...	15–20
Potatoes	...	42
Rice, clean	...	45–48

Substance	Specific gravity	Weight, lb. per cu. ft.
Agricultural Products (*Continued*)		
Rice grits	...	42–45
Rye	...	44
Sawdust	...	13
Shavings, wood	...	15
Starch	...	45
Sugar, raw	...	55–65
Sugar, refined	...	50–55
Sugar beet pulp, dry	...	12–15
Sugar beet pulp, wet	...	25–45
Tanbark	...	55
Tankage	...	60–62
Turpentine	...	54
Wheat	...	48
Wool	...	82
Salts and Industrial Chemicals		
Alum, lumpy	...	50–60
Alum, pulverized	...	45–50
Bakelite	...	30–40
Baking soda	...	50–55
Borax, powdered	...	50–55
Bone black	...	20–25
Carbon black, powdered	...	4–6
Carbon black, gran.	...	25
Char	...	45
Chalk, crushed	...	85–90
Chalk, pulverized	...	70–75
Charcoal	...	18–38
Gutta-percha	...	61
Glass, common	...	156
Glass, crystal	...	184
Glass, plate	...	161
Gypsum, calcined	...	55–60
Gelatin, gran	...	33
Hides green	...	85
Iodine	4.95	309
Lithopone	...	45–50
Paraffin cake	...	45
Phosphorus, white	...	115
Phosphate, acid	...	60
Phosphate, gran.	...	90
Rosin	...	168.6
Rubber, caoutchouc	...	59
Rubber goods	...	94
Salt, coarse	...	45–51
Salt, dry, fine	...	70–80
Salt, granulated, piled	...	48
Saltpeter	...	67
Sewage sludge	...	40–50
Soap, powdered	...	20–25
Soda, caustic	...	88
Soda ash, dense	...	55–65
Soda ash, light	...	20–35
Starch	...	96
Sulfur, lump	...	80–85
Sulfur, powder	...	50–60
White lead	...	35–55
Zinc oxide	...	10–35

TABLE XVI.—RESISTANCE OF VALVES AND FITTINGS TO THE FLOW OF FLUIDS[1]

Pipe size, inches	Gate valve	Globe valve	Angle valve	90-deg. elbow	45-deg. elbow	Close return bend	Tee straight through	Tee through side outlet	Multiplying factor for water and nonviscous liquids
½	0.4	10	5	0.9	0.6	2.2	0.7	2.2	1.07
¾	0.5	15	7	1.3	0.9	3.4	1.1	3.4	1.08
1	0.7	20	10	1.8	1.2	4.4	1.5	4.4	1.09
1¼	0.9	25	12	2.2	1.5	5.5	1.8	5.5	1.10
1½	1.1	30	15	2.7	1.8	6.7	2.2	6.7	1.11
2	1.5	40	20	3.6	2.5	9.0	3.0	9.0	1.13
2½	1.8	50	25	4.4	3.0	11.0	3.7	11.0	1.14
3	2.2	60	30	5.3	3.7	13.5	4.4	13.5	1.15
3½	2.5	70	35	6.2	4.3	15.5	5.1	15.5	1.16
4	3.0	80	40	7.0	5.0	18.0	6.0	18.0	1.17
5	3.6	100	50	9.0	6.2	22.5	7.4	22.5	1.19
6	4.4	120	60	10.5	7.5	27.0	9.0	27.0	1.20
8	6.0	160	80	14.0	10.0	36.0	12.0	36.0	1.21
10	7.5	200	100	18.0	12.5	45.0	15.0	45.0	1.22
12	9.0	240	120	21.5	15.0	56.0	18.0	56.0	1.22

[1] Walworth Co.

NOTE.—Tabular values indicate equivalent length of straight pipe in feet, having same resistance as fitting. Values given are for steam, air or gas.

For water and nonviscous liquids, multiply tabular values by the factor given in the last column. Values given are for screwed fittings. For flanged gate valves, multiply tabular values by 0.80; for globe valves, by 0.96; for angle valves, by 0.90; for elbows, tees and bends by 0.75.

APPENDIX B

ELEMENTARY PROBLEMS

Exercise I—Simple Foundations

Problem 1. Foundation for a Cast-iron Shaft.—Design the concrete foundation for an obelisk with solid cast-iron shaft, total height 15 ft. from base to tip. The shaft is to have a square base, 4 ft. on the side; the solid cap of the shaft is to be of aluminum, 3 ft. high, tapering from the peak to the top section of the cast-iron part which is 2 ft. square. The shaft is to be located on alluvial soil, 2 ft. above grade.

Problem 2. Foundation for a Water Tank.—Design a concrete foundation for a standard Lancaster vertical, cylindrical, water-storage tank, 45 ft. in diameter and 30 ft. high, of standard sheet-steel construction. The tank is to be located in the rear of the power plant, on gravel soil, 1 ft. above grade.

Exercise II—Equipment Foundations

Problem 1. Design of Supports and Foundations for Horizontal Standard 15,000-gal. Riveted Pressure Tank for Storage of Hot Oil.

Specifications.

A. Tank.

1. Size 40 ft. long by 8 ft. diameter.
2. Working pressure, 45 lb. Factor of safety, 4.
3. Convex heads, radius = diameter of tank; follow A.S.M.E. Code for unfired pressure vessels.
4. Materials of construction, boiler plate; Underwriters' Laboratories, National Board of Fire Underwriters.
5. Allowable temperature variations, −20° to 660°F.
6. Center line of tank, 8 ft. above grade.
7. Drain cock on end, 4 ft. above finished floor.

B. Supports.

1. Lugs, six in number, cast iron, 8-in. bearing face.
2. Weight to be uniformly distributed.
3. Lugs to rest on I-beams; these beams to rest on pipe supports.
4. Tank to be anchored only at center.
5. Pipe supports must be anchored to piers using floor flanges.
6. Supports must be properly cross-braced.

C. Piers.

1. Concrete, two, to project 2 in. above finished floor.
2. Piers to extend across tank.

3. Use reinforcement rods.
4. Floor, 4 in. thick, top 1 ft. above grade.

D. Floor, 4 in. thick, top 1 ft. above grade.
E. Location, outside, on sandy soil.

Problem 2. Design of Supports and Foundations for a Vertical Tank for Storage of 52°Bé. H_2SO_4.

Specifications.

A. Tank.
1. Lead-lined, using 10 lb. per square foot sheet lead.
2. Sides, ¼-in. boiler plate.
3. Ends, 5⁄16-in. boiler plate, convex, radius = diameter of tank.
4. Diameter of tank, 8 ft.
5. Length of tank at edge, 20 ft.
6. Lugs, cast iron, four.

B. Supports.
1. Support plane, 16 ft. above grade.
2. Pipe, standard, also fittings.
3. Center of tank, 14 ft. above grade.
4. Supports must be anchored to piers.

C. Piers.
1. Four in number.
2. To extend 12 in. above grade.
3. Run reinforcement rods from concrete into supports.
4. Shape, frustum of pyramid.

D. Location, outside, gravel and sand soil.
E. Temperature variations, −20° to 220°F.

Problem 3. Design of Supports and Foundations for Chemical Equipment.

Sketch layout and elevation for specific unit operation equipment installed in chemical engineering unit operation laboratory. Use local data and conditions for specifications.

Exercise III—Drainage

Problem 1. Design of Sewer System for Plant.

Required: Layout and elevation, details of special drainage.

Specifications.

A. Building.
1. Size, 128 by 41 ft.; standard industrial building, side bays 20 ft. 6 in. wide; each bay 16 ft. long; each bay with central floor drain with pitch of 1 in. in 8 ft. from outer edge of bay to drain in center (narrow dimension of building fronting on street).
2. Property and building line abutting sidewalk; sidewalk, 5 ft. wide; parking area, 10 ft. wide; paved street, 20 ft. wide.
3. Curtain walls, 8 in. thick; concrete floor, 4 in. thick; grade level, 932 ft.

B. Sanitary and chemical facilities necessary.

1. Capacity: calculate; provide four times capacity for central main to take care of expansion for chemical line; sanitary water demands, 75 gal. per person per day.
2. Equipment.
   a. Vertical reaction vessel, 6 ft. diameter, 1,000 gal. capacity, with connections for direct dumping into sewer. In right rear corner of building, edge of tank 1 ft. from walls.
   b. A 2-ft. 6-in. by 10-ft. condenser and 6- by 10-ft. still, in right front corner of building; still located with center point 8 ft. from front and side wall; closed condenser 8 ft. from front wall and 34 ft. from right side of building, fed by ½-in. water line. Drain for condenser to have check valve and running trap. Water pressure in ½-in. line, 50 lb.; line 100 ft. long and delivery 30 ft. high.
   c. Toilet facilities: urinals, stools, showers, wash and locker facilities for 20 men per shift (three shifts). Space 20 ft. 6½ in. by 16 ft. in left rear of building provided. Proper sanitary traps and all fittings. Toilet facilities and space for three women adjoining office in left front of building; office in 20-ft. 6-in. by 16-ft. space; no floor drain. Drinking fountain in front of building.
   d. Roof drainage to run toward rear of building, with collector to carry to left rear from right rear. Storm water to run into sanitary drain; sanitary drain to run into city sewer.
   e. Chemical line to drain back to industrial sewer 10 ft. from rear wall.
3. Location. On highway; 24-in. city sewer is in center of roadway 6 ft. below grade level.
4. Materials. Use good industrial grade of materials.
   a. Central drainage pipes, terra cotta.
   b. Branch lines, cast iron.
   c. Manholes and cleanouts.
   d. Floor drains, countersunk in floor, with strainer cap and bell trap.
   f. Vent traps, valves, etc. All cast-iron fittings and pipe should be "heavy."
5. Calculate excavation at $2.50 per cubic yard.

NOTE.—In bill of materials provide 2 per cent extra for breakage in all piping.
Use 40 per cent, then 20 per cent, "off" listed quotations. Add 20 per cent for labor.

Problem 2. Design of Drainage System for Chemical Engineering Building.

Sketch layout and elevation for chemical engineering unit operation laboratory using grid-covered trench system. Use local data and conditions for specifications.

Exercise IV—Piping Installations

Problem 1. Design of Steam Service for Chemical Plant Equipment.

Specifications.

A. Supply line properly lagged; 150-lb. gage steam pressure; pipe 4 in. diameter.
B. Service for vertical still, open kettle, steam-jacketed kettle and ejector for pumping liquid from one tank to elevated tank. Locate service lines at 14-ft. level on hangers or supports.
C. Steam pressure to vertical ether still, 60 lb.; 1,000 lb. steam per hour at 5,000 ft. steam velocity.
D. Steam pressure to jacketed kettle, 30 lb.; 500 lb. steam per hour at 5,000 ft. steam velocity.
E. Steam pressure to ejector, 25 lb.
F. Silencer on steam line in open kettle.
G. Floor plan of equipment (on centers from lower left, southwest corner of area).
 1. Vertical still, 43 ft. right, 11 ft. up.
 2. Open kettle, 40 ft. right, 93 ft. up.
 3. Jacketed kettle, 40 ft. right, 84 ft. up.
 4. Lower storage tank; 40 ft. right, 100 ft. up.
 5. Elevated tank, 30 ft. right, 108 ft. up.
H. Dimensions of equipment with elevations.
 1. Vertical still, diameter 3 ft., height 22 ft.
 2. Open kettle, diameter 3 ft., depth 2 ft., top level 2 ft. 8 in.
 3. Jacketed kettle, diameter 2 ft. 6 in., depth 4 ft. 8 in., top level 6 ft.
 4. Lower storage tank, diameter 4 ft., depth 4 ft., top level 8 ft.
 5. Elevated storage tank, diameter 6 ft., depth 6 ft., top level 20 ft.
I. Ejector to empty lower tank in 20 min.
J. Use return line for condensate from steam traps.
K. Use reducing valves, properly by-passed, where needed.
L. Safety valves should be used on all equipment.

List bill of materials and cost data.

Problem 2. Design of Steam Service for Chemical Plant Equipment.

Specifications.

Sketch layout and elevation of high- and low-pressure steam service to local chemical engineering unit operation equipment.

Problem 3. Design of Water Supply for an Industrial Plant.

Sketch and Layout: General, pumphouse, tank, valves, hydrant. List bill of materials, pipe-laying costs.

Specifications.

A. Supply from river.
B. Intake is screened pipe leading to well in pumphouse.
C. Pumphouse to protect pump and motors.
D. Centrifugal pump is direct-connected, motor-driven; set above flood level; maximum rise of river, 10 ft.
E. Provision for priming pump; foot valve on supply to pump.
F. Property line 1,000 ft. from pump.
G. Grade level at property, 960.2 ft.
H. Elevation at pump, 860.2 ft.
I. Grade level at point 600 ft. from pumphouse is 960.2 ft.
J. Pipe to be laid below frost line.
K. Water tower of sufficient capacity and elevation to provide for pressure, plant fire protection demands and for sufficient storage against temporary breakdowns.
L. Provide cleanout valve, check valve, and gate valves in line from tank to pumphouse.
M. Gate valves to shut off supply from river to well in pumphouse.
N. Plant requires 50,000 gal. water per 16-hr. day.
O. Fire hydrant in building area.
P. Building 60 ft. inside property line.
Q. Provide 30 lb. pressure in building on second floor at 22-ft. level.

Problem 4. Design of Water Supply for an Industrial Plant.

Specifications.

Sketch layout and elevation for water supply of water service in local chemical engineering laboratory.

Problem 5. Layout and Bill of Materials for Chemical Process Lines and Fittings to Vertical Reaction Vessel.

Supply bill of materials for all piping and fittings necessary to supply chemical solutions from main supply lines to reaction vessel.

Specifications.

A. Vessel: 45 ft. over-all length; 12 ft. diameter; convex ends, radius of ends, 12 ft.; drainage outlet 8 in. with lever-gate valve on bottom head center, 4 ft. off the floor; both fittings and screw boiler flange on vessel are furnished with vessel.
B. Main supply lines: Horizontal; on-side, 6 in.; off-side, 8 in.; resting on concrete piers 2 ft. above finished floor; 6-in. line center 5 ft. from edge of tank; 8-in. line center 18 in. from center of 6-in. line; main lines must be cut and tees supplied.
C. Chemical service lines: 4-in. and 2-in. lines rising vertically from 8-in. and 6-in. lines, respectively, to a common feed line into the inlet on reaction vessel, each to be provided with a return sweep to prevent siphoning from common feed line; gate valves on each service line to be placed at 6-ft. level.

Use all flanged fittings, extra strong, for increased life of setup.

D. Floor: 4 in. thick, 1 ft. above grade line of 960.02 ft.

E. Location: inside chemical engineering building.

Consider labor for installation at 20 per cent cost of material. Deduct 40 per cent and 20 per cent from list prices for materials cost.

Exercise V—Equipment Assembly Drawing

Problem 1. Design of Chemical Stoneware Absorption Tower for SO_2 Absorption System.

Specifications.

A. Scrubbing length, 45 ft.; 30-in. diameter tower sections.

B. Packing.

1. One-third diaphragm, 4-in. size.
2. One-third spiral, 3-in. size.
3. One-third Raschig rings, 1-in. size.

C. Stoneware aspirator to pull gases through tower.

D. Lantern consisting of Pyrex brand glass-pipe section to be fitted into system at convenient and accessible level, between tower and aspirator.

E. Tower saucer on bottom and tower cover on top, distributor on top section.

F. Tower to rest on concrete base, built upon floor.

G. Sufficient supporting plates to carry the packing rings.

H. Tower to be supported by wooden scaffolding.

I. Scaffold risers to be made of 1- by 8-in. boards, crosspieces of 2 by 4 in.; supports to be properly cross-braced.

J. Pump to transfer water at 25°C. to top of tower at rate of 1,200 gal. per hour, producing a 1 per cent solution for product at base of tower.

Sketches required.

A. Sketch layout and setup.

B. One detailed sketch of tower showing arrangement of sections of tower; break sections to show nature of packing.

C. One detailed sketch of tower showing arrangement of supporting structure.

Problem 2. Assembly Sketch of Local Chemical Engineering Equipment.

Sketch a layout and elevation of one of the local units in the chemical engineering unit operation laboratory, complete with all piping and accessories. Include a bill of materials.

Exercise VI—Power Transmission

Problem 1. Sketch and Bill of Materials for Power Transmission Setup.

Specifications.

A. Building 128 by 60 ft.

1. Standard industrial building, flat-roof type.
2. Exposed beams.

B. Equipment to be driven.

1. Dryer: Ruggles-Coles X-A for drying clays; 1 r.p.m. for drum, gear drive, and speed reducer (10: 1).
2. Centrifugal: Tolhurst, center-slung, 48-in. basket; belt driven; r.p.m. normal, 750; locate in line near Bauer mill.
3. Bauer mill: 24-in. plates; each 1,800 r.p.m.; differential speed, 3,600 r.p.m.; 50-hp. requirement; located near outside side wall of building.

C. Main shaft lengthwise of building, operating at 250 r.p.m.

D. Locate motor, shafting, beam clamps and hangers, pillow blocks, gear supports, idlers, pulleys, etc.

Do not sketch equipment in detail; only portion connected with motivation mechanism.

Layout and elevation sketches and bill of materials desired.

Problem 2. Sketch and Bill of Materials for Local Power Transmission Setup.

Specifications.

Include location on switches, and motors in relation to serviced equipment.

EXERCISE VII—ILLUMINATION, VENTILATION AND HEATING

Problem 1. Lighting, Ventilation and Heating for Standard Factory Building

Select factory building of standard design for chemical plant, containing dryer, Bauer mill, centrifugal (see VI-1), and steam processing equipment. (See IV-1.)

Locate lighting outlets, unit heaters and ventilators.

Specifications.

A. Roof: flat, steel deck, Maizewood insulation; four-ply, built-up construction.

B. Walls: side-wall panels 6 ft. high; remainder, steel windows.

C. Doors: steel, sliding.

D. Windows: center-pivoted; steel.

E. Floors: concrete.

F. Ventilation: provide sufficient changes to agree with requirements for factory.

G. Heating: unit heaters; low-pressure steam.

H. Lighting: standard factory outlets; sufficient for chemical plant.

I. Location of plant, Pittsburgh, Pa.

Problem 2. Lighting, Ventilation and Heating of Chemical Engineering Building.

Make three separate sketches of local installation of electric lighting, of ventilation, including dust and fume elimination, and of heating installation. Also, submit report on evaluation of local conditions of lighting, ventilation and heating as compared with standard requirements.

Exercise VIII—Flow Sheets

Problem 1. Materials Flow Sheet.

Draw a materials flow sheet for the production of a specified chemical commodity.

Problem 2. Equipment Flow Sheet.

Draw an equipment flow sheet for the production of chemical commodity specified in Problem 1.

Exercise IX—Specifications

Problem 1. Raw Materials Specification.

Write specifications for the raw materials and finished products to be produced in Exercise VIII.

Each specification should be written on a separate sheet.

Problem 2. Equipment Specification Form Sheet.

Develop an "information required" form sheet for a specified unit of laboratory or plant operation equipment.

Problem 3. Equipment Specification.

Write an equipment specification for a unit of chemical plant equipment. Also, add a requisition to the purchasing department for this unit.

Problem 4. Pump and Motor Specifications.

Write complete pump and motor specifications for such units connected with equipment used in Problem 3. Also, submit requisition for each unit. Each specification should be written on a separate sheet and should constitute a complete presentation of facts necessary for ordering a duplicate of present pumps or motors.

Exercise X—Plant Location Map

Sketch a map of the native state or commonwealth. Locate principal cities and centers of chemical commodity production. Use legend to identify commodity production.

APPENDIX C

STUDENT DESIGN PROJECTS ASSIGNMENTS

In the following pages are given four projects, each one of which covers in eight problems all the calculations and designs that would be required in the preparation for an actual process plant. Not only is each project carried through the stages of flow diagrams, specifications, plans, bills of material and preconstruction cost accounting but it also includes the preparation of operating instructions for use in starting up the plant. During the preconstruction stages it is necessary for the designer always to keep in mind the number and type of operators needed. Being well versed in the performance characteristics of each piece of equipment and knowing its required operating schedule, he is in a position to give instructions on the operation of the plant, assuming his design is correct and the plant is normal. It is necessary that the operating instructions laid down by the designer be the basis for tuning up the plant; any variations from his instructions should be made only as a result of the experience gained after the plant has been put into efficient operation.

Project I—Ferrous Sulfate Recovery Plant

Design a plant for the recovery of ferrous sulfate from the waste pickle resulting from the pickling of steel in a galvanizing plant.

A galvanizing plant uses 100 tons or 50°Bé. sulfuric acid every 24 hr. in the pickling of steel; before it is used this acid is diluted to 18°Bé. When exhausted insofar as pickling is concerned, the waste pickle liquor leaves the vats as a 25 per cent solution of ferrous sulfate containing 2 per cent sulfuric acid, and at a temperature of 175°F. This liquor is drained from the pickling vats through a header into a waste-liquor storage reservoir built underground.

From the pickle-liquor storage reservoir the liquor is to be pumped into neutralizer tanks containing scrap iron for neutralization of the acid; 48 hr. at 170°F. is considered sufficient to complete neutralization. The neutralized liquor is then to be pumped through filters to remove insoluble sludge before concentration in special evaporators. Crystallization to monohydrate is to be effected in the evaporators and the crystals are to be permitted to fall into a sump where temperature is maintained above 171°F.

The wet crystals are to be removed by means of a pump or mechanical rake, centrifuged and then cooled. The mother liquor from the centrifuge is to be returned to the sump. The dry crystals are to be conveyed to storage bins, preparatory to bagging, barreling and transfer to freight cars.

The pumps, conveyors, agitators and other motivating equipment are to be operated from a lineshaft, except that vacuum pump on the evaporator is to be steam driven, the exhaust steam from this pump to be used in the first effect evaporator. If approved plant layout does not permit economical use of shafting for acid liquor pumping, a separate motor drive may be used for such purpose.

Project II—Deodorized Soybean Oil Plant

Design a plant for the deodorization of raw soybean oil obtained from an expressing plant handling 50 tons of raw beans, according to general practice; the deodorized oil to be used for oleomargarine.

The deodorizing plant is to consist of a closed tank or deodorizer in which the oil is to be processed; equipment for heating the oil within the deodorizer while steam is blown through the oil; means for maintaining a high vacuum within the deodorizer; and equipment to cool and filter the oil after deodorizing.

The oil to be deodorized is to be heated by circulating it through a heater at 125°C., steam is to be injected into the oil; the deodorizing cycle to be 8 hr. The vacuum is to be obtained by use of Nash-Hytor vacuum pumps. Cooling is to be accomplished by dropping the deodorized oil into a vacuum cooling tank equipped with cold water coils.

Project III—Sodium Chlorate Plant

Design a chemical plant for the production of 4,000 lb. of sodium chlorate per 24 hr. by the Liebig method.

Salt from Louisiana will be shipped in, put into solution in wooden tanks, purified by sodium carbonate treatment to separate out the calcium and magnesium, neutralized with hydrochloric acid and then electrolyzed using Nelson cells; the chlorine gas is to be piped to a mixing chamber, where it is to be mixed with the brine-caustic solution to form sodium hypochlorite; this solution is heated to 90°C. to transform the hypochlorite to chlorate. The sodium chlorate-sodium chloride solution is then evaporated in triple-effect evaporators and the sodium chloride is removed; when evaporated to a concentration of 74.1 per cent sodium chlorate, and a residual salt content of 0.41 per cent, the solution has a gravity of 1.65; then the solution is transferred to crystallizers and cooled. The crystallized sodium chlorate is centrifuged from the mother liquor and dried in a steam-heated rotary drier before placing in storage. The separated sodium chloride is washed free from sodium chlorate by washing with sodium hydroxide solution and returned to the system for electrolyzing.

The average current efficiency of the Nelson cell is to be considered as 86 per cent, and the chemical efficiency rated at 80 per cent. All but 2 per cent of the sodium chloride is to be considered as recoverable. The Nelson cell is to operate under optimum conditions on a 26.4 per cent sodium

chloride solution at 55°C., producing a solution of specific gravity 1.23 and containing 9.67 per cent sodium hydroxide and 14.52 per cent residual sodium chloride.

Project IV—Butane Oxidation Plant

Design a plant for the production of solvents by the method of partial oxidation of butane.

A natural gasoline plant has available, as a by-product from the natural gasoline refinery, 60,000 cu. ft. of butane per day, based on standard gas conditions. This by-product is to be utilized by oxidizing in the vapor phase the butane under controlled conditions to produce partial-oxidation products, totaling 159 lb. per 1,000 cu. ft. of butane, the product consisting of aldehydes, alcohols, ketones and acids, according to the following analysis:

	Per Cent
Acids, calculated as acetic	4.0
Esters as ethyl acetate	0.6
Aldehydes	
Acetaldehyde	18.5
Formaldehyde	15.0
Higher aldehydes	4.2
Alcohols, calculated as methanol	22.2
Ketones, calculated as acetone	9.5
Water	26.0

The conditions of the partial-oxidation process are the injection of a mixture of air and butane vapor, in a ratio of 10:1, into a stream of inert gas resulting from the elimination of the condensable vapors at 350 lb. pressure. In order to carry the air-butane mixture through the system, a recirculation of inert gas is maintained at a ratio of 140:1, inert gas to butane. The temperature of the furnace must be maintained, so that the reaction coils heat the gas up to 720°F. at the exit from the furnace. The reaction furnace is to be heated with butane; steam is to be generated by using butane fuel. Compressors are to be operated with internal-combustion engines using butane as the fuel. Water supplied for cooling is to be available at a range of 75° to 90°F.

The product obtained by oxidation of butane is to be subjected to fractionation, separating into three main fractions, *viz.:* (1) pure acetaldehyde, (2) a crude methanol fraction, and (3) a residue to be wasted. The second fraction is redistilled after treatment with caustic to polymerize the aldehydes, and the vapors are further treated by washing countercurrently in a 33 per cent caustic solution.

DESIGN PROJECT PROCEDURE

Senior students in the curricula of chemical engineering usually have a training based upon the application of the fundamentals of chemistry, physics, mathematics, mechanics, engineering, English, and economics acquired in the first three years. At

this stage students have completed all laboratory work in unit operations and have had four quarters of unit-operations theory, completed all junior courses in chemistry, organic and physical. By the winter quarter they will have had at least one quarter of industrial chemistry lecture and industrial stoichiometry, and an introduction to literature review. The student is now capable of studying a process problem involving economics of processes, personnel, materials and heat balances, unit operations, thermodynamics, kinetics, stoichiometric calculations, report writing, and drawing of process equipment assemblies.

Such a correlation course should be essentially on development and may be named design, or development, or both. In this course the reaction kinetics are presented from the engineering point of view, taking up where physical chemistry left off, treating experimental data by graphical calculus to predict optimum conditions of operation for pilot-plant and plant-scale performance. Also, the course should deal with the visualization of processes in terms of equipment, men, materials, and money.

At this point the one phase of work that the general run of students lacks is a correlation of design principles to actual cases in one's own professional field. Often this is accomplished by invoking the practice of applying the principles in report writing for junior chemical engineering unit-operation assignments. If not, then some time should be devoted to assigning simple problems for the practice of calculation, sketching, and report writing, including detailed sketches of assemblies of available chemical engineering pilot or commercial plant equipment. Bills of materials should also be included in such assignments.

Selection of Project.—The next step probably should involve the selection of problems on the preparation and production of some marketed chemical commodity. Whether to give individual or group problems depends upon the size of the class. A class of five to ten can be taught individually, but the difficulty increases with the larger classes, and it may be necessary to assign two to a topic or as many as four. The problem should be solvable with a fair degree of ease and should be on some commodity already on the market that is produced by several correlated unit processes and unit operations.

Preliminary Survey.—Following the assignment of the process topic or commodity should be the preliminary survey. A review

of the literature on many approved processes by which the commodity can be made should then be undertaken, the chemistry involved carefully scrutinized, preliminary flow sheets drawn, and some preliminary costs figured. Then a decision of the particular process to be undertaken may be arrived at by weighing all known facts. The order of procedure in the preliminary survey to select most feasible process reaction or reactions may be as follows:

1. Literature review.
2. Raw materials considerations (theory, all possible reactions).
3. Market considerations (curves for all products and all possible raw materials, for 15 years).
4. Lowest possible costs (based on all possible raw materials and theoretical yields).
5. Selection of one or more basic processes.

Small-scale Experimentation.—The next step should be acquisition of experimental data through laboratory studies. In this laboratory work the students should prepare the commodity according to the process selected, for the purpose of acquiring necessary data for plant design. All thermal, chemical, and physical data not available from literature reviews must be acquired. A material balance should be made. In order to obtain yield and other general data on process reactions studied, the students should follow this order of procedure:

1. Probable costs (yield and reaction study on 1-lb. batch).
2. Materials and equipment requirements.
   Observations essential are:
   a. Type of reaction.
   b. Quality of product.
   c. Quantity of product.
   d. General solubility.
   e. Separation characteristics.
   f. Heat considerations.
   g. General operations required.

Development Laboratory Experimentation.—Following the laboratory- or beaker-scale experimentation when the students are satisfied as to feasibility of the preparation and have enabled themselves to acquire sufficient information to undertake a large batch operation, such as 2 to 10 pounds, a "pail-and-tub" proc-

ess laboratory study should then be undertaken; attention should be paid to the engineering considerations involved in the production of the commodity. In order to obtain engineering data essential for the design of pilot-plant investigation of the production of the commodity selected, the following considerations may be important:

1. Procedure essentials.
2. Raw material characteristics.
3. Chemical flow sheet.
4. Corrosion characteristics.
5. Effect of impurities.
6. Heat considerations.
7. Unit operations required.
8. Material handling.
9. Storage.
10. Engineering flow sheet.

Pilot Plant Design.—A general departure from unit process studies is that which involves laboratory data first in pilot-plant design. Immediately following the acquisition of laboratory data from the beaker and the 2- to 10-lb. batch experimentation, a review of pertinent facts on the process should be undertaken, using some kind of check list.[1] In order to design a pilot plant for the production of 100 lb. per day, the following considerations may be important:

1. Equipment flow sheets.
2. Selection of equipment.
3. Selection of materials.
4. Procedure necessary.
5. Labor requirements.
6. Plan.
7. Elevation.

Commercial Unit Calculations.—Then should follow commercial unit design calculations. The detailed calculations necessary to obtain quantitative considerations for the design of the commercial unit should require the major attention and application of mental energy in the design course. The sequence of this phase of the study may be according to the following outline:

[1] *Chem. Met. Eng.*, **43**, No. 2 (1936).

1. List of laboratory and plant data.
2. Quantitative reaction calculations.
3. Equipment calculations.
4. Flow of materials.
5. Material balance.
6. Thermal balance.
7. Quantitative flow sheet.

Commercial Unit Design.—The final step in the study should be the coordination of all chemical and engineering data obtained and their translation into a definite organized unit. Access must be had to trade literature for selection of types and specific pieces of equipment. Capacities and performance should be studied. Preliminary layouts should be attempted, and the best flowing arrangement obtained. Organization of the equipment by means of templates will give the student a better picture of the possibilities of different layouts. After arriving at the most desirable layout, actual drawing of the plan and elevation of the assembly should be undertaken followed by preconstruction costing. In order to design a commercial unit, including housing for the production of the specified commodity, the following considerations may be important:

1. Specifications of equipment.
2. Specifications of materials.
3. Selection of commercial equipment.
4. Plan.
5. Elevation.
6. Location of plant.
7. Operating instruction for labor.
8. Selection of personnel.
9. Preconstruction costing.
10. Production costs per unit of material.

Notebooks.—Notebooks must be kept with a daily log of all observations and data. Each page should have a title and date, and at the end of each period a brief résumé must be written of the day's work, signed by initials of the worker and someone who was with him in the laboratory. Notebooks should be deposited with the instructors.

Reports.—Weekly reports to the class are essential, and weekly written reports should be made. The student should receive practice in presentation. Calculations and reasons for making

certain decisions should be presented concisely to the class for criticism. The discussions should be informal.

Final Compilation.—At the end of the year a complete report should be turned in which includes all calculations, flow sheets, material balances, plans, and layouts, and a carefully executed drawing on plans and elevation of the completed plant, with such detailed drawings as may be necessary to clarify the drawing.

PROBLEMS

1. Prepare an equipment flow diagram.
2. Prepare a quantitative flow diagram.
3. Write specifications for all equipment.
4. Make cardboard cutouts to scale for all pieces of equipment, processing and storage facilities.
5. Draw a complete assembly plan and elevation.
6. Prepare a bill of materials on all buildings and equipment.
7. Prepare a report on possible net earnings of the plant.
8. Prepare operating instructions in detail for tuning up the plant.

APPENDIX D

PROJECT PRECONSTRUCTION-COST DATA

A compilation of the preconstruction-cost data on the ferrous sulfate plant project (Chap. IX, p. 197) is given below, with the purpose of showing a method of presentation of data and information needed to determine the costs of a contemplated plant before work can be started on the erection of a plant, or even before appropriations are made for the construction of the plant.

1. Reservoir and Neutralizing Tanks

Excavation at $0.10 per cubic yard	$ 89.00
Acid-proof brick at $70 per thousand + 2 per cent + 20 per cent	431.00
6 tanks at $800 + 20 per cent	5,760.00
1-in. brass coil at $0.10 per foot	75.00
12 1- by 1- by 14-ft. bolsters; 42 2-in. by 6-in. by 12-ft. bolsters } at $180 per 1,000 cu. ft.	453.00
Railing	
140 ft. 1¼-in. pipe at $0.23 per foot[1]	18.60
20 "All-slip" crosses at $1.40[1]	16.10
10 "All-slip" caps at $0.45[1]	2.60
10 square floor flanges at $0.40	2.30
20 anchor bolts at $0.05	1.00
Tank fittings	
12 1-in. brass unions at $1.60[1]	11.10
12 1-in. brass 90-deg. elbows at $0.63[1]	4.35
12 1-in. brass nipples at $1.16[1]	8.00
6 2-in. brass nipples at $2.60[1]	9.00
6 2½-in. brass nipples at $3.90[1]	13.10
12 1-in. flanges at $2.28[1]	15.70
6 2-in. flanges at $2.35[1]	8.10
6 2½-in. flanges at $2.45[1]	8.50
60 Duriron coil supports at $0.10 per pound	990.00
Subtotal	$7,916.45
Installation, 20 per cent	1,583.55
Total	$9,500.00

[1] Less 20 per cent, less 40 per cent, plus 20 per cent.

2. Filters and Accessories

2 Shriver filter presses, flush, iron, 1½- by 1½-ft. plates and frames (24) at $336	$ 672
Installation and accessories (pumps, piping, strainers) 50 per cent on filter costs	336
Total cost	$1,008

3. Evaporators

2 Evaporators, horizontal, copper, cast-iron body, each 400 sq. ft. evaporating surface at $3,780	$ 7,560
3 Pumps	790
Condensers, 15 per cent of base evaporator costs	1,134
Accessories, 5 per cent of base evaporator costs	378
Installation, including setting and lagging, 25 per cent of base evaporator and auxiliaries	2,465
Total costs	$12,327

4. Crystallizers

2 Miter gears, diameter 8.36 in., No. 612, H. Channon Co., at $9.10	$ 18.20
4 Cast-iron split pulleys, diameter 22 in., face, 4 in., at $10.95	43.80
2 7-ft. lengths shafting, 2 in. diameter Link-Belt	17.88
2 14-ft. lengths shafting, 2 in. diameter Link-Belt	25.76
2 8-in. quick-opening gate valves, Crane No. 971, at $80	160.00
2 Cast-steel tees, 8-in., No. 264 D, Crane, at $51	102.00
6 Cast-steel tees, 8-in., No. 260 D, Crane, at $24	144.00
22 ft. 8 in. wrought-iron pipe at $2.50 per foot	55.00
1,160 ft. ¾-in. copper coil pipe at 10 cts. per foot	116.00
6 6-in. H-columns, 15 ft. long	123.12
1 8-in. H-column, 15 ft. long	29.34
1 8-in. I-beam, 2 ft. long	2.46
8 Lugs	12.00
2 7-in. channels, 13 ft. long	16.00
4 Agitator blades at $2.50	10.00
2 Wedgegate valves, No. 467, Crane, 8-in., at $90	180.00
2 Crystallizer tanks, ⅜-in. plate, with cone bottom	2,700.00
Subtotal	$3,747.56
Plus 25 per cent for installation cost	939.14
Total	$4,686.70

5. Centrifugals

2 Hepworth 30-in. centrifugals; speed 1,200 r.p.m.; 23 to 25 hp., at $1,000 each	$2,000
Accessories, 20 per cent of base centrifugal cost	400
Installation, 25 per cent of base centrifugal cost	600
Total	$3,000

6. Dryer

1 American process dryer, C-2, steam-heated air, countercurrent, rotary	$3,500
29 ft. galvanized sheet-metal vent pipe, 2 ft. diam.	7
5 Pillow blocks, plain babbitted, $1\frac{7}{16}$ in., at $3.20 each	16
5 ft. steel shafting, $1\frac{7}{16}$ in., at $0.60	3
2 Cast-iron pulleys, 10 in. diam., at $5 each	10
2 Cast-iron pulleys, 12 in. diam., at $6 each	12
Installation, 25 per cent of base and accessory costs	887
Total	$4,435

7. Elevators

2 Class C vertical elevators, steel casing, two head sections	$270
2 intermediate sections	36
2 boots, 2-C (Link-Belt)	206
1 swinging spout, 10 ft.	15
Installation, 25 per cent of base and accessory costs	132
Total	$659

8. Conveyors

25 ft. Standard helicoid steel conveyor, 6 in., at $3 per foot	$ 75
1 Countershaft box end, 6 in.	27
1 Right-angle drive, 6 in.	45
1 Box end, 6 in.	4
Installation, 20 per cent of base costs	30
Total	$181

9. Storage Bin

(Accepted cost of structural steel in place is $6 per 100 lb.)

Quantity	Item and size	Weight	Total cost
6	30-ft. H-columns, 6 in.	22.8 lb.	$ 246
4	9-ft. 6-in. I-beams, 12 in.	50 lb.	114
10	13-ft. 3-in. I-beams, 5 in.	12.25 lb.	98
2	13-ft. 3-in. channels, 5 in.	11.5 lb.	18
8	9-ft. 6-in. angles, 5 by 7⁄16 in.	....	65
18	9-ft. 6-in. angles, 3 by 7⁄16 in.	....	86
8	9-ft. angles, 3 by 7⁄16 in.	....	36
2	7-ft. angles, 3 by 7⁄16 in.	....	7
2	4-ft. 6-in. angles, 3 by 7⁄16 in.	....	5
3	9-ft. channels, 4 in.	6.25 lb.	10
	1,000 sq. ft. 3⁄8-in. boiler plate	....	845

Total costs (in place)................................... $1,430

10. Chemical Lines

Quantity	Type and size	Unit price	Total
46 ft.	2½-in. Cast-iron pipe	$ 0.24	$ 10.74
7	2½-in. Cast-iron gate valves	4.80	33.60
2	2½-in. Cast-iron crosses	2.70	5.40
1	2½-in. Cast-iron tee	1.40	1.40
60 ft.	2-in. Duriron pipe	......	88.80
25 ft.	3-in. Duriron pipe	......	15.20
1	2-in. Duriron tee	7.20	7.20
2	2-in. Duriron crosses	13.50	27.00
2	2-in. Duriron ells	6.00	12.00
1	3-in. Duriron ell	6.90	6.90
7	2-in. Duriron plug valves	26.00	182.00
1	Cameron steam pump, No. 33	......	395.00

Total............................ $ 785.24

Installation and breakage, 40 per cent. 314.10

Grand total.................................... $1,099.34

11. Steam Distribution

Quantity	Size in inches, or style	Material	Unit price	Total cost
2	No. 22	Std. wall brackets	$ 11.00	$ 22.00
1	Style C	Pipe support	2.80	2.80
8	Style J	Pipe hangers	3.00	24.00
1	Style SS	Pipe hangers	1.50	1.50
1	Style Q	Solid anchor	18.75	18.75
1	No. 11	20-in. rad. expansion band	15.00	15.00
1	3	Ex. hvy. C.I. tee (screw)	3.00	3.00
1	3	Ex. hvy. C.I. tee (flanged)	9.15	9.15
1	3 × 4 × 1½	Ex. hvy. C.I. tee (flanged)	13.50	13.50
1	4 × 4 × 3	Ex. hvy. C.I. tee (flanged)	13.50	13.50
1	3 × 3 × 1	Ex. hvy. C.I. tee (screw)	3.75	3.75
1	1	Ex. hvy. C.I. tee (screw)	0.55	0.55
2	4 × 4 × 1	Std. C.I. tees (screw)	2.00	4.00
1	4 × 4 × 1¼	Std. C.I. tees (screw)	2.00	2.00
1	4 × 3 × 4	Std. C.I. tees (flanged)	9.00	9.00
1	4 × 4 × 2	Std. C.I. tees (screw)	2.00	2.00
1	2 × 2 × 1	Std. C.I. tees (screw)	0.47	0.47
1	1¼	Std. C.I. tees (screw)	0.23	0.23
1	1¼ × 1¼ × ½	Std. C.I. tees (screw)	0.27	0.27
3	1	Std. C.I. tees (screw)	0.15	0.45
1	1	Std. C.I. cross tee (screw)	0.27	0.27
4	3	Ex. hvy. C.I. ells (screw)	2.00	8.00
1	4	Std. C.I. ell (screw)	1.20	1.20
4	3	Std. C.I. ell (screw)	0.75	3.00
1	2	Std. C.I. ell (screw)	0.28	0.28
4	1¼	Std. C.I. ell (screw)	0.16	0.64
1	½	Std. C.I. ell (screw)	0.06	0.06
1	1	Std. C.I. ell (screw)	0.11	0.11
2	3	W.I. close nipples	0.48	0.96
4	4	W.I. close nipples	0.85	3.40
1	1¼	C.I. flanged union	0.64	0.64
4	1	C.I. flanged unions	0.52	2.08
1	3	Solid plug	0.38	0.38
2	No. 2	Crane open-float steam traps	35.00	70.00
2	½	Webster steam traps	3.55	7.10
2	....	Radiators	6.00	12.00
1	3	No. 7 globe valve	34.00	34.00
2	4	No. 71 globe valves	90.00	180.00
1	4	No. 972 press. reg. valve	145.00	145.00
3	1¼	No. 1-B globe valves	2.52	7.56
1	½	No. 1-B globe valve	1.00	1.00
2	1	No. 7 globe (h.-p.) valves	2.80	5.60
1	1½	No. 7 globe (h.-p.) valve	5.50	5.50
7	1	No. 1-B globe (l.p.) valves	1.80	12.60
1	3	No. 1 globe (l.p.) valve	14.40	14.40
1	2	No. 1-B globe (l.p.) valve	5.30	5.30
210 ft.	3	Ex. hvy. W.I. pipe	1.03	236.30
20 ft.	1	Ex. hvy. W.I. pipe	0.22	4.40
19 ft.	1¼	Ex. hvy. W.I. pipe	0.30	5.70
60 ft.	4	Std. W.I. pipe	1.09	65.40
30 ft.	2	Std. W.I. pipe	0.37	11.10
45 ft.	1	Std. W.I. pipe	0.17	7.65
70 ft.	3	Std. W.I. pipe	0.765	53.55
112 ft.	1¼	Std. W.I. pipe	0.23	25.76
38 ft.	½	Std. W.I. pipe	0.085	3.23
		Gaskets	....	10.00
Subtotal				$1,090.09
Installation and breakage, 40 per cent				436.04
Total				$1,526.13

12. Water Distribution

Quantity	Item and sizes	Unit cost	Total cost
35 ft.	½-in. galvanized iron pipe	$ 0.085	$ 2.98
10 ft.	¾-in. galvanized iron pipe	0.115	1.15
6 ft.	1-in. galvanized iron pipe	0.17	1.02
135 ft.	1½-in. galvanized iron pipe	0.275	37.20
4	¾-in. brass bibb cocks for hose	25.80 per doz.	8.60
2	½-in. brass, low-pressure, globe valve	1.00	2.00
2	1½-in. brass, low-pressure, globe valve	3.50	7.00
1	5-in. brass, gate valve	110.00	110.00
8	½-in. malleable iron 90-deg. elbow	0.10	0.80
2	¾-in. malleable iron 90-deg. elbow	0.15	0.30
12	1½-in. malleable iron 90-deg. elbow	0.35	4.20
2	5-in. malleable iron 90-deg. elbow	4.00	8.00
4	½-in. malleable iron tees	0.11	0.44
1	1½ × 1 × ¾-in. malleable-iron reducing tees	0.70	0.70
2	1½ × 1½ × ½-in. malleable-iron reducing tees	0.70	1.40
2	1½ × 1½ × ¾-in. malleable-iron reducing tees	0.70	1.40
1	5 × 1½ × 1½-in. malleable-iron reducing tees	8.00	8.00
1	¾-in. malleable-iron Y-bend	0.50	0.50
3 lb.	1½-in. tinned straps	0.18 per lb.	0.54
1 lb.	¾-in. tinned straps	0.18 per lb.	0.18
2 lb.	½-in. tinned straps	0.18 per lb.	0.36
	From catalog of James Robertson Manufacturing Co.		
1	Urinal, Plate G-1600, Glass B	46.50	46.50
1	Toilet, "Kenwood," Plate G-910	33.50	33.50
1	Toilet, "Acme," Plate G-913	45.00	45.00
1	Shower head, Plate G-270	3.30	3.30
1	Wash sink, 36 by 18 inches, Plate G-533	24.00	24.00
1	Lavatory, "Rowland," Plate G-458	15.75	15.75

Subtotal	$364.82
Installation and breakage, 40 per cent	155.93
Total	$520.75

13. Sewer Layout and Mother-liquor Return

Quantity	Items and size	Unit price	Total
9	10 × 10-in., 2-in. outlet floor drains	$ 0.60	$ 5.40
2	5-in. dia. 2-in. outlet floor drains	7.00	14.00
125 ft.	2-in. W. I. std. pipe	0.37	47.25
110 ft.	2-in. C. I. soil pipe std. single hub	0.26	28.60
25 ft.	4-in. C. I. soil pipe std. single hub	0.46	11.50
50 ft.	8-in. C. I. soil pipe std. single hub	1.40	70.00
50 ft.	6-in. C. I. soil pipe std. single hub	0.70	35.00
14	2-in., 45-deg. elbows	0.40	6.40
1	4-in. check valve	27.00	27.00
2	4 × 2 × 4-in. Y's	0.85	1.70
1	4 × 8-in. reducer	2.50	2.50
3	2 × 8-in. tees	6.00	18.00
30 ft.	10-in. terra-cotta	......	10.00
6	2 × 6-in. Y's	1.80	10.80
1	2 × 2 × 2-in. long Y	2.25	2.25
1	6 × 4 × 6-in. tee	1.80	1.80
1	6 × 4 × 4 × 6-in. double Y	6.15	6.15
4	4-in. 45-deg. elbows	0.60	2.40
1	Manhole and cover, 257 lb.	0.07	18.00
650	Bricks for manhole	0.02	13.00
	Excavation for manhole	......	5.00

Subtotal.. $336.00
Installation, breakage, 40 per cent...................... 134.40

Total.. $470.40

14. Power Shafting

Quantity	Item	Unit price	Total
5	Dodge adjustable ball-and-socket bracket hangers	$14.95	$ 74.75
5	Dodge adjustable ball-and-socket post hangers	15.95	79.75
2	Dodge adjustable ball-and-socket drop hangers	4.95	9.90
42 ft.	Dodge round steel shafting (2$\frac{3}{16}$ in.)	1.00	42.00
29 ft.	Dodge round steel shafting (2$\frac{5}{16}$ in.)	1.00	29.00
6 ft.	Dodge round steel shafting ($\frac{5}{16}$ in.)	1.00	6.00
5	Dodge steel split pulleys (4 × 12 in.)	4.65	23.25
2	Dodge steel split pulleys (8 × 6 in.)	4.60	9.20
2	Dodge steel split pulleys (8 × 16 in.)	8.25	16.50
2	Dodge steel split pulleys (6 × 12 in.)	5.35	10.70
3	Dodge steel split pulleys (6 × 6 in.)	4.05	12.15
1	Dodge steel split pulleys (5 × 10 in.)	4.35	4.35
1	Dodge steel split pulleys (17 × 30 in.)	24.75	24.75
320 ft.	Dodge rubber belting (4 in.)	1.00	320.00
96 ft.	Dodge leather belting (6 in.)	1.80	172.80
44 ft.	Dodge leather belting (10 in.)	3.60	158.40

Subtotal	993.50
Installation, 25 per cent.	248.25
Total	$1,241.75

15. Electrical Equipment

45 Outlets at $1.75	79.75
300 ft. conduit at $9.00 per 100 ft.	27.00
4 Extension cords	16.00
12 Single-pole switches	6.00
3 Distribution cabinets	21.00
Installation, 20 per cent	29.95
	$ 179.70
1 60-hp., 220-volt, a.-c. slip-ring, induction motor	1,580.00
Wiring and accessories	150.00
Installation, 20 per cent.	346.00
Total	$2,255.70

16. Excavations and Foundations

Curtain wall excavation: 280 ft. by 4 ft. deep by 16 in. wide = 63 cu. yd. at \$3 per cubic yard		\$ 189
Concrete floor, 6 in. thick, 90 by 30 ft.	50 cu. yd.	
34 by 32 ft.	21 cu. yd.	
Piers, 24 at 0.5 cu. yd. each	12 cu. yd.	
Equipment foundations	9 cu. yd.	
Curtain walls	32 cu. yd.	
Total	124 cu. yd.	
at \$12 per cubic yard		1,488
Total		\$1,677

17. Runway

Costs of Materials	
190 ft. of 2 × 12 in.	\$ 68.40
724 ft. of 2 × 6 in.	130.32
338 ft. of 4 × 4 in.	54.00
182 ft. of 2 × 4 in.	21.78
84 ft. of 2 × 2 in.	5.04
8 lb. of 16-penny nails	0.32
8 lb. of 20-penny nails	0.32
4 lb. of 40-penny nails	0.16
Costs of Labor	
16 hr. for 2 carpenters at \$1 per hr. per man	32.00
Total	\$312.34

INDEX

Q

R

U

W

Z